SD
11
A3525
no.
161

**nited States
epartment of
griculture**

orest
ervice

orth Central
Forest Experiment
Station

General Technical
Report **NC-161**

PROCEEDINGS
9th Central Hardwood Forest Conference

Purdue University, West Lafayette, Indiana

March 8-10, 1993

Each registrant of this conference was eligible for 12 hours of Continuing Forestry Education (CFE) credit through the Society of American Foresters.

The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service or Purdue University of any product or service to the exclusion of others that may be suitable. Statements of the contributors from outside the U.S. Department of Agriculture, Forest Service or Purdue University may not necessarily reflect the policy of the Department or the University.

Remarks about pesticides appear in some technical papers constrained in these proceedings. Publication of these statements does not constitute endorsement or recommendation of them by the conference sponsors, nor does it imply that uses discussed have been registered. Use of most pesticides is regulated by State and Federal Law. Applicable regulations must be obtained from the appropriate regulatory agencies.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish and other wildlife—if they are not handled and applied properly. Use all pesticides selectively and carefully. Follow recommended practices given on the label for use and disposal of pesticides and pesticide containers.

North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
Manuscript approved for publication July 23, 1993
1993

9th CENTRAL HARDWOOD FOREST CONFERENCE

Proceedings of a Meeting
Held at
Purdue Univeristy
West Lafayette, IN
March 8-10, 1993

Edited by
Andrew R. Gillespie, Purdue University
George R. Parker, Purdue University
Phillip E. Pope, Purdue University
George Rink, USDA Forest Service, North Central Forest Experiment Station

SPONSORED BY:
Department of Forestry and Natural Resources, Purdue University
and the North Central Forest Experiment Station, USDA Forest Service

ACKNOWLEDGEMENTS

The editors extend special thanks to all individuals who served as manuscript reviewers. Their efforts improved the quality of the Proceedings.

FOREWORD

This proceedings resulted from the ninth in a series of biennial conferences held at various Universities throughout the Central Hardwood Forest Region. The conference was successful in providing a forum for dicussion of the biology and management of hardwood forests by scientists from throughout the eastern United States. Papers contained within this proceedings provide a continuing documentation of the broad array of research programs attempting to understand this diverse forest resource. As with previous proceedings topics range from basic biology and ecological processes to economic value and management.

The social and biological characteristics of the Central Hardwood Region make it unique in comparison with other forest regions of the United States. One-fourth of the United State's human population reside in this region. Approximately 90% of the land is in private ownership and public lands tend to be small and fragmented with private inholdings. The papers presented in this proceedings are important to the long-term management of this unique region.

REVIEW PROCEDURES

Each manuscript published in these proceedings was critically reviewed by at least two scientists with expertise in disciplines closely aligned to the subject of the manuscript. Reviews were returned to the senior author, who revised the manuscript appropriately and resubmitted it in a diskette format suitable for printing by the North Central Forest Experiment Station, USDA Forest Service where they were edited to a uniform format and type style. Manuscript authors are responsible for the accuracy and style of their papers.

CONTENTS

Page

Perspectives, Trends, and Forestry Opportunities ... 1
Calvin F. Bey

Central Hardwood Forests: Recent Trends in a Robust Resource ... 8
T.W. Birch, D.A. Gansner, and W. H. McWilliams

Growth and Shifts in Eastern Hardwood Lumber Production ... 17
William G. Luppold and Gilbert P. Dempsey

Oak Silviculture, Management, and Defoliation Effects in France and Germany ... 23
Kurt W. Gottschalk

FOREST BIOLOGY—Moderator: Jerry Van Sambeek

Comparative Physiology of a Central Hardwood Old-Growth Forest Canopy and Forest Gap ... 46
A.R. Gillespie, J. Waterman, and K. Saylors

Bark Thermal Properties of Selected Central Hardwood Species ... 55
Gretel E. Hengst and Jeffrey O. Dawson

Eco-physiology of *Acer saccharum* Trees on Glade-like Sites in Central Missouri ... 76
Eric J. Rhodenbaugh and Stephen G. Pallardy

The Endangered Karner Blue Butterfly (Lepidoptera: Lycaenidae): Biology, Management Considerations, and Data Gaps ... 83
Robert A. Haack

A Graphic Technique for Identifying Superior Seed Sources for Central Hardwoods ... 101
Fan H. Kung and George Rink

Phenology and Recruitment of Ohio Buckeye and Sugar Maple in Illinois Forest Stands ... 107
Michelle Henderson, Jeffrey O. Dawson, and Evan H. DeLucia

FOREST PROTECTION—Moderator: Philip Marshall

Impacts of Pear Thrips on a Pennsylvania Sugarbush: Third Year Results ... 119
Thomas E. Kolb and Larry H. McCormick

Forest Stand Conditions After 13 Years of Gypsy Moth Infestation ... 130
David L. Feicht, Sandra L.C. Fosbroke, and Mark J. Twery

Susceptibility of Oak Regeneration in Clearcuts to Defoliation by Gypsy Moth ... 145
Ray R. Hicks, Jr., Robert M. Fultineer, Barbara S. Ware, and Kurt W. Gottschalk

Predictability of Gypsy Moth Defoliation in Central Hardwoods: A Validation Study ... 156
David E. Fosbroke and Ray R. Hicks, Jr.

Mapping the Defoliation Potential of Gypsy Moth ... 172
David A. Gansner, Stanford L. Arner, Rachel Riemann Hershey, and Susan L. King

SILVICULTURE—Moderator: Mark Coggeshall

Artificial Regeneration of Northern Red Oak in the Lake States With a Light Sherlterwood: A Departure From Tradition 185
Ronald M. Teclaw and J.G. Isebrands

Survival and Growth for the First-growing Season of Northern Red Oak (*Quercus rubra* L.) Seedlings Underplanted in Mixed Upland Hardwood Stands in South Central Iowa 195
Robert E. Bardon and David W. Countryman

Vegetative Propagation of Mature and Juvenile Northern Red Oak 210
James J. Zaczek, K.C. Steiner, and C.W. Heuser, Jr.

Survival and Growth of Planted Northern Red Oak in Northern West Virginia 222
Charles A. McNeel, David M. Hix, and Edwin C. Townsend

Group Selection—Problems and Possibilities and for the More Shade-intolerant Species 229
Paul A. Murphy, Michael G. Shelton, and David L. Graney

Logging Damage to Residual Trees Following Partial Cutting in an Green Ash-Sugarberry Stand in the Mississippi Delta 248
James S. Meadows

—Moderator: Randall Heiligman

Hardwood Regeneration Twenty Years After Three Distinct Diameter-limit Cuts in Upland Central Hardwoods 261
Randall B. Heiligmann and Jeffrey S. Ward

Factors Limiting Northern Red Oak Reproduction in Pennsylvania 271
Russell S. Walters and L.R. Auchmoody

FOREST ECOLOGY—Moderator: David Hix

Vegetation of Loess Bluff Ravines in the Jackson Purchase Region of Kentucky 281
William S. Bryant

The Missouri Ozark Forest Ecosystem Project: The Effects of Forest Management on the Forest Ecosystem 289
Brian Brookshire and Carl Hauser

An Ecological Classification System for the Central Hardwoods Region: The Hoosier National Forest 308
James E. Van Kley and George R. Parker

STAND INVENTORY, YIELD, AND DYNAMICS—Moderator: Stephen Shifley

A Comparison of Forest Dynamics at Two Sites in the Southeastern Ozark Mountains of Missouri 327
Michael A. Jenkins and Stephen G. Pallardy

Influence of Crown Class, Diameter, and Sprout Rank on Red Maple (*Acer rubrum* L.) Development During Forest Succession in Connecticut 342
Jeffrey S. Ward and George R. Stephens

Formulating a Stand-growth Model for Mathematical Programming Problems in Appalachian Forests 353
Gary W. Miller and Jay Sullivan

FOREST ECONOMICS AND MARKETING—Moderator: W.L. Mills

Production Rates and Costs of Group-Selection Harvests with Ground-Based Logging System 363
Chris B. LeDoux, Michael D. Erickson, and Curt C. Hassler

Profitability of Precommercially Thinning Oak Stump Sprouts 373
John P. Dwyer, Daniel C. Dey, and William B. Kurtz

Relative Price Trends for Hardwood Stumpage, Sawlogs, and Lumber in Ohio 381
John E. Baumgras and William G. Luppold

Public Land Use and Potential Impact on Missouri's Forest Products Industry 390
Bruce E. Cutter and William B. Kurtz

WILDLIFE MANAGEMENT AND SCIENCE—Moderator: Robert Swihart

The Effect of Small Rodents on Northern Red Oak Acorns in North-central West Virginia 400
Linda S. Gribko and David M. Hix

Developing Regeneration in Woodlots at Gettysburg National Military Park 409
Todd W. Bowersox, Gerald L. Storm, and Walter M. Tzilkowski

Deer Exclusion Effects on Understory Development Following Partial Cutting in a Pennsylvania Oak Stand 418
Larry H. McCormick, John W. Groninger, Kathy A. Penrod, and Todd E. Ristau

Lease Hunting in the Central Hardwood Region: An Examination of Tradeoffs 428
Stephen M. Bratkovich and Donald W. Floyd

FOREST SOILS AND TREE NUTRITION—Moderator: Mark David

The Effects of Pruning Treatments and Initial Seedling Morphology on Northern Red Oak Seedling Growth 436
Donald J. Kaczmarek and Phillip E. Pope

Performance of Hardwoods Planted With Autumn Olive After Removing Prior Cover 447
Felix Ponder, Jr.

Interplanting Woody Nurse Crops Promotes Differential Growth of Black Walnut Saplings..... 455
J.O. Dawson and J.W. Van Sambeek

POSTER SESSION

A Review and Validation of the Implan Model for Pennsylvania's Solid Hardwood Product Industries 465
Bruce E. Lord and Charles H. Strauss

Advance Reproduction and Other Stand Characteristics in Pennsylvania and French Stands of Northern Red Oak 473
Kim C. Steiner, Marc D. Abrams, and Todd W. Bowersox

The Effects of Gypsy Moth Defoliation on Soil Water Chemistry 484
Thomas R. Eagle, Jr., and Ray R. Hicks, Jr.

Selected Soil Enzyme Activities in an Oak-Hickory Forest Following Long-Term Prescribed Burning 485
M.R. Bayan and F. Eivazi

Management and Prediction of Red Oak Decline in the Missouri Ozarks 488
James J. Wetteroff and John P. Dwyer

An Assessment of Advance Regeneration and Herbaceous Communities in Pennsylvania Forests 489
W.H. McWilliams, S.L. Stout, T.W. Bowersox, and L.H. McCormick

Characterizing Forest Composition of the Allegheny Mountains Using Extensive Forest Inventory Data 490
W.H. McWilliams, R. Riemann Hershey, D.A. Drake, and C.L. Alerich

Development of an Ecological Classification System for the Wayne National Forest 491
David M. Hix and Andrea M. Chech

Early Development of Mixed-species Stands on the Wayne National Forest 502
Eric R. Norland and Dr. David M. Hix

Interactions Between Competing Vegetation, Herbivores, and Environmental Conditions Affecting Regeneration of Northern Red Oak (*Quercus rubra* L.) 511
David S. Buckley, Terry L. Sharik, Judson G. Isebrands, and William J. Mahalak

Soil Nitrogen Mineralization and Cellulose Decomposition in Northern Red Oak Stands With Four Levels of Canopy Cover in Northern Lower Michigan 512
Choonsig Kim, Terry L. Sharik, Martin F. Jurgensen, Richard E. Dickson, and William J. Mahalak

Effect of Ectomycorrhizae on 1-year-old Northern Red Oak Seedlings in Response to Overstory and Understory Manipulations in Oak and Pine Stands 513
Minyi Zhou, Terry L. Sharik, Martin F. Jurgensen, Dana L. Richter, and William J. Mahalak

Groundfire Effects in a Sapling-sized Oak-maple 514
Jeffrey W. Stringer

Perspectives, Trends, and Forestry Opportunities

Calvin F. Bey [1]

Abstract: It is clear that our perspective, profession, society and approach to natural resource management has changed a lot over the last century and particularly over the last 30 years. We have adjusted to many changes and will be challenged to adjust to many more in the future. Understanding the global environmental perspective and expected trends should help us as we deal with the implications of change in our research and management positions. The trends for increased use of multidisciplinary approaches, concern for ecological management, global involvement, attention to risk assessment, and the use of science in establishing policy will make for an exciting professional future. A talented, professional diverse workforce, with a passion for solving problems, serving people, producing resources, and caring for the environment will be needed to meet the challenges.

INTRODUCTION

Thank you for the invitation to participate in this 9th Central Hardwood Forest Conference. I'm pleased to be here to share a few thoughts--hopefully pertinent to you as managers, specialists and researchers in the Central Hardwood region. It's good to be in the Midwest and on a University campus. Some familiar faces in the audience bring back pleasant memories of my past work in this region.

I'd like to share a few ideas with you about changes in natural resource management that seem to be on the horizon. I will discuss the implications of change for natural resource management and research, and hopefully present some clear challenges to you--for now and in the future.

I would like to begin with a quote that is pertinent to a major point that I want to make today. A New York City Commissioner said it this way, "The environment is no longer an environmental issue." He went on to explain how environmental issues are completely intertwined with the whole fabric of society. In a similar way, I see natural resource management and research intertwined with the political, social, economic, ethics, and science issues of today. These major issues are critical and central to our quality of life and the sustainability and health of the planet Earth. As natural resource professionals, we have a key role in addressing the science problems and in serving a special set of societal needs.

USING DIFFERENT PERSPECTIVES

Perhaps you, like me, have climbed a firetower or two in years past. I remember that experience as physically exhilirating, topped off with a magnificent view, looking further out than ever possible from the ground. From each step along the climb to the top there was a slightly different view, a different perspective. You don't have to climb firetowers to recognize this, but I believe in our jobs that it is important to listen and reflect on different perspectives from time to time. Do those different perspectives cause us to see things from a different point of view, question old or current operational practices or even examine the principles we learned in school? I hope so. I like to think that examining different perspectives is part of our continuing education process.

---

[1] Staff Assistant, Forest Management Research, USDA Forest Service, Box 96090, Washington DC 20090-6090.

Malcolm S. Forbes said, "Education's purpose is to replace an empty mind with an open one." If we use that definition of education, then examining different perspectives should be a routine practice. Oliver Wendell Holmes, stated it a little differently: "The human mind, once stretched to a new idea, never goes back to its original dimensions." New perspectives, like new ideas, can cause us to change.

I'm sure that in studying and managing hardwoods, we all want to see progress. In a broad context, just what does "progress" mean? Rosabeth Moss Kanter said "the art of progress is to preserve order amid change, and change amid order." That challenge of striking a balance between preserving order and adjusting to change has been central to our forestry profession in America for a long time.

WHERE HAVE ALL THE CHANGES BEEN

What are the significant changes that have taken place in forestry in America over the past century? Perhaps some understanding and appreciation of the past can provide us with some insights as we prepare for the future.

How have we changed our perspective concerning the purpose and value of forests? For convenience, I would like to break the past century into three phases: (1) exploitation (up to 1930); (2) protection (1930-60); and (3) management (1960 to present). In phase 1, forests were viewed as obstacles to agriculture; as a primary source of material for fences, bridges, railroads and charcoal; and often disposed of by burning. Around 1930 we moved to an era of protection, phase 2. In those 30 or so "protection" years, we reduced wildfire burns by a factor of 10. We initiated forest management practices and restored a lot of the cut-over and burned-over lands, especially in the East. Timber production was considered to be the primary purpose of forest lands. In phase 3, roughly the past 30 years, we accepted forest land as the producer of many goods and services. The forest became the provider of many resources--timber, water, wildlife, fisheries, recreation, minerals, etc. It appears that we are now moving into a new era, where forest values and land stewardships are central themes. What the forest "is" and the condition of the forest gets equal consideration with what the forest produces. Only time will reveal how this theme plays out.

Along with the changes concerning the purpose and value of forests, management and research on forest lands became much more diverse and complex. These are significant shifts and ones that some other resource-oriented professionals (e.g. oil, coal, and gas producers) have not had to adjust to in such a major way over the years. At the very least, these shifts in how we view and use our forests have improved our ability to adjust to change and made for interesting debates within the profession.

What about changes in our forestry profession? It's gone from primarily foresters to a broad mix of natural resource, social, and other specialists. It's adopted a land ethic that "requires" members to advocate and practice land management consistent with ecologically sound principles. We have moved to become much more involved in the international arena, and we wrestled with issues on licensing, professional education qualifications, and even the question of what constitutes our profession.

What are the changes in our approach to natural resource management? Think for a minute how we did it historically. In the past, professionals were educated and expected to know what was best for the land, best for the mankind, and how to balance the two. Sometime during the 1960-70's, society decided it was appropriate to speak out on how the environment was managed or mismanaged. There were lots of milestones in this time period, e.g. the first Earth Day, the Multiple Use Act, the Wilderness Act, the Land and Water Conservation Fund Act, the Historic

Preservation Act, the National Environmental Policy Act, the Endangered Species Act, and the National Forest Management Act—to name just a few. We addressed other issues dealing with fish, wildlife, clean water, wild horses and burros, insecticides, rodenticides, fungicides, resource planning, clean air, etc. That public involvement movement has grown to a point where forest managers now seriously consider what land management practices the public will and won't accept. That public (individuals, interest groups, Congressional representatives, etc.) are not bashful about expressing opinions that go beyond State and National Forest boundaries.

Within our profession we have welcomed and promoted public involvement and participatory management. We have placed greater emphasis on human values, as well as land and resource protection and restoration. Listen to the titles of three books reviewed in the January 1993 Journal of Forestry. They are "Balancing Act: Environmental Issues in Forestry," "Global Imperative: Harmonizing Culture and Nature," "On Common Ground: Managing Human-Planet Relationships." Our profession was not involved in reading and reviewing those kinds of books 10 or 15 years ago. These three examples demonstrate the kinds of changes that are occurring.

Have there been changes in society? Of course. In fact, they are the primary drivers in the other changes. We have more people. They are more concentrated in cities and they have a higher standard of living. We have developed into a luxury-laden American society that increasingly places higher and higher values on natural resource protection and restoration. That luxury and those values prompts conflicts and challenges--as a rule it's utilization versus preservation debates.

It is clear that our perspective, our profession, our approach to natural resource management and our society has changed a lot during the last century and particularly over the last 30 years. We could debate whether the glass is half empty or half full, but I think that we have adjusted to the major changes fairly well. I suggest that one measure of successful adjustment is the fact that there has been a continued need by the customers for our services. Certainly some of you have had some pain caused by these adjustments and I would not pretend that it has been an easy road. Nor would I say that the road ahead is without its dangerous curves and icy spots.

I expect that we will see even more changes in the future. The question of balance will not diminish. Amid all the changes, how can we preserve order? We need some stability. We can't afford to start over with every new idea. Throwing out the good with the bad is an expensive way to operate. Let me recommend one idea that might be useful. I believe that it will be easier to run our organizations if it is clear to everyone in the organization which major items are and are not negotiable for change. This can be done by establishing and adhering to the mission, vision, goals, and principles of operation which are at the core of the organization. This should help to provide a work environment that gives a sense of stability.

THE LARGER PERSPECTIVE

I expect that some of you would argue that we and society have gone too far in public involvment--that the professional can no longer do his/her job, that work efficiency is greatly reduced, and that the protectionism movement is wildly out of control. Some others would likely argue that we have been far too slow in adjusting to change—that we are not listening to what the public wants us to do. Where do we draw the line for public involvement and participatory management involving decisions about how our natural resources are used, restored, and protected?

Lets digress and take a world perspective peek on what is happening to the environment. I refer you to *Our Common Future*, A United Nations Commission on Environment and Development report on the status of the world. The Report is often quoted with regards to the topic of sustainable development—meeting the needs of the present without compromising the ability of future generations to meet their own need. Here is a statement from this 1983 report: "*Our Common Future* serves notice that the time has come for a marriage of economy and ecology, so that governments and their people can take responsibility not just for environmental damage, but for the politics that cause the damage. Some of these policies threaten the survival of the human race. They can be changed. But we must act now." This report is a serious request for us to look at environmental and development problems beyond local, state, and national borders.

I refer you also to *State of the World 1993*, published by Worldwatch Institute, another international group concerned about getting a sense of the condition of the world's environment. Here are a couple summary statements for perspective: "Today environmental degradation is directly affecting national and global economic trends." "Soil erosion, thinning of the ozone shield, air pollution, and increased flooding caused by deforestation are all taking their toll. Rangelands and oceans are being pushed to their limits, and their productivity is beginning to fall." Here is another call to understand our problems within the international framework, the larger perspective.

How do Americans feel about the environmental issues? The Times-Mirror Magazine National Environmental Forum Survey, completed in March, 1992, reports that 30 percent of Americans think of themselves as "active environmentalists" and another 52 percent say they are "sympathetic" to environmental concerns. Nearly two-thirds think environmental laws and regulations have not gone far enough. When faced with a choice, two-thirds come down on the side of the environment rather than economic growth. Perhaps most surprising, Americans are split evenly on the assertion by the World Watch Institute that the 1990's is the last decade when humanity will have a chance to save the Earth from environmental catastrophe. Whether it is true or not that we are on the brink of environmental disaster, it is important that we as natural resource managers and researchers understand how the public perceives the issues.

Do ideas and statements that I have just presented have anything to do with management and research in the Central Hardwood region? I would say "yes." In a very real sense the global environmental issues shape our ideologies, our programs, and our priorities. And if nothing else, they help us to understand why people want to be involved in land management decisions. It seems like we in forestry are caught in the middle. Art Smyth, President of the Society of American Foresters during 1990, said it very well in the 1993 issue of the Journal of Forestry, "I think I speak for all the foresters of my generation when I say that the last few years have seen our forestry world "turned upside down." Art hastens to add, and I agree, these are exciting times; we have much to learn; we have made some mistakes in our past; but we haven't fallen off the earth. As I read Art's message I hear him calling for progress--preserving order amid change and changing amid order.

TRENDS FOR THE FUTURE

I am sure that you can see many problems to be addressed. You know the scientific questions, and I assume that your agenda provides a sense of current priorities for Central Hardwoods. I see a lot of historic and current topics on the list. This may be most appropriate, but hopefully, some of your efforts are addressing topics that are oriented toward the issues of the future.

In general, the following trends seem to be the major drivers from which all pressures on natural resource use and protection originate:

(1) Population increases and changing demographics will put more pressure on the use of all natural resources;

(2) There will be increasing public pressure for protection and restoration of natural resources and the environment; and

(3) Global concerns, involvement, and cooperation will increase.

Within this larger context, what are the natural resource and forest management trends? I believe that we will see increased attention given to ecological understanding, longer rotations, larger landscapes, new uses and new values for the land and natural resources, and special emphasis given to the condition of the resources. Regarding the condition of the resources, there will be increased emphasis on forest health and sustainability. We will hear a lot about ecosystems and ecosystem sustainability. By ecosystem sustainability I mean, the ability of the system to maintain biological diversity, resiliency to stress, and a capacity for renewal over time, while providing a flow of products or benefits that meet current or future human needs.

The emphasis described above are now embodied in the USDA Forest Service, National Forest System philosophy for forest and range management. In that philosophy, it is referred to as Ecosystem Management. In the National Forest System there are additional components of Ecosystem Management that deal with the operational aspects of the philosophy. These include choosing a desired future condition, looking at past conditions, examining natural system options, public involvement, partnerships, and guidelines for clearcutting. Its a philosophy that includes the human and economic components, commodity production, and protection. The dilemma of balancing production and protection still exist. An increasingly difficult challenge is the balancing of current production needs with the long-term desired future condition of the resource. Natural resource management of the future promises to be exciting.

IMPLICATIONS FOR MANAGEMENT AND RESEARCH

With those ideas on the history, perspective, and trends in mind, I suggest there are some significant implications for future management and research. For forest managers, I see the assignments becoming increasingly complex. There will be a need for highly educated and skilled managers. The ability to fit together all the pieces of the resources will require someone with strong analytical and synthesizing abilities. Managers will need to be visionary, take a broad perspective, and be problem solvers. Natural resource education will be important, as will the ability to understand complex ecological processes. Is that asking too much for managers? I hope not. They will be making long-term decisions that impact the land, influence resource availablility of the future, and effect peoples lives.

There will be an increased need for specialists, who can assist the managers. Specialist of many types will be needed to understand the function and structure of the broader ecosystem. Specialists will be needed to understand scale relationships—how do we scale-up from our understanding of organisms, to stands, populations, watersheds, and landscapes. We will need a lot more than just wildlife, fisheries, soils, and recreation resource specialists. How about microbiologists, population geneticists, insect ecologist, and modelers for starters. Although emphasis will need to be on the multidisciplinary approach, the need for specialists will increase.

Should there be any changes in how we view professional development in preparing for the future? I suggest that managers and specialists will need to stay in one location for longer periods of time—to better understand the problems and to observe how ecosystem processes unfold. Improved data bases, Geographic Information Systems, decision support systems and better ways to characterize risks will undoubtedly be available to display management options, but there will be no substitute for the intimate land/resource knowledge for understanding what is best for maintaining sustainability.

For researchers, I see a parallel track. We'll need a cadre of superb analytical people and synthesizers, who can bring together information from many independent studies. These researchers will need to be good at sorting out the priority research needs and in designing multidisciplinary studies that test some broad-scale hypotheses. I see these integrating type of studies as capstones after some of the specific, discipline-oriented research has been completed. This is an area that deserves special attention but should be approached with caution. Studies are likely to be large and consequently very expensive. Quality assurance for multidisciplinary type studies must be rigorous. If the questions asked and hypotheses being tested are mushy, so too will be the answers. Controls, replication, randomization, and the level of uncertainty tolerable in the answer should be thoroughly addressed.

Managing research programs will not get any easier. Demands for answers to complex practical problems will likely increase. There will be requests and temptations to get into research on the latest problem-of-the month. In some cases, researchers will be asked to cooperate in demonstration projects and management trials. Its important that the researchers and managers make clear to each other their expectations of results for the projects being developed. The arena of quasi-scientific projects is fraught with dangers. Managers are prone to expect clear-cut and definitive answers to general questions. Researchers are prone to hedge on answers and want more specific testing. In these endeavors, managers and research need to "Beware."

There will be an increased desires to use science in establishing policies. Along these lines, some cautions are in order. While science should serve as the foundation for policymaking by establishing the expected results (options) and corresponding levels of risk, researchers must be alert to pressures for answers for research results with "correct" answers. It will be important to separate what is scientifically sound from what are research implications and expert opinions. While all may be useful in making management and policy decisions, and used as evidence in court, there are differences that should be made clear by researchers. I see an increasing need for quality assurance emphasis at all major research institutions. As researchers we need to be careful that we do not get in the policymaking game on the basis of science alone. Policy will generally deal with broad-based issues, where social, economic, and political factors are also involved.

Research planning will increase in importance. Whether you are in industry, university, federal, or nongovernment organizations it will serve you well to have a documented plan for research. It should be strategic in the sense that it contains a vision, broad goals, and be long-term in nature. The plan should be coordinated and complementary with goals of other organizations. Such plans should change with time as problems are solved and new needs arise. The plans should be widely shared with other professionals. In general, I see too few of these plans. I suspect it is because there are too few.

Technology transfer will increase in importance. I'm a great believer in sharing what we learn in research with others. My early experience in Forest Service research at Carbondale, Illinois, and working hand-in-hand with Burl Ashley in State and Private Forestry, was an excellent example of how to get our walnut genetics and culture research implemented. There was an excellent feedback loop on current problems and everyone, especially the customer, benefited. I see a need for increased efforts in this type of technology transfer.

Within the context of increased partnerships and technology transfer, I believe that research must adhere to a certain level of independence. Rigorous adherence to scientific operational principles and the independence to present results, even if it is not consistent with current policy, must be maintained. To do otherwise will be to destroy research credibility. There will also be a need to express research results through risk assessment processes.

Natural resource managers and researchers of the future in the Central Hardwood region, just like elsewhere, will need to give increased attention to education. Whether you call it continuing education or a life-long learning philosophy doesn't matter. Individuals without personal motivation, and/or a strong support organization will not serve society well. The society of the future will be different than it is today. Some in society will view the earth as an opportunity to explore and exploit the natural resources. Others will view the earth as the natural healer and provider that cares for us all. Most people will have views that are inbetween. It will be our responsibility to have the expertise that presents the options to serve them all.

Oprah Winfrey is quoted as saying, "when I look at the future, it's so bright it burns my eyes." I believe that the future for natural resource management and research will be bright. There will be problems in natural resource management but we will solve them. It will take a plethora of talented and diverse men and women from the crosscut of society. We will need people who are inspired, with a passion for solving problems, serving people, producing resources, and caring for the environment. I hope that all of you are working to develop that cadre of caretakers, managers, specialists, and researchers.

I would like to close with the same notion that I began. Perhaps we can learn from the New York City Commissioner who said "The environment is no longer an environmental issue." I say to you, natural resource management and research is no longer a natural resource nor even an environmental issue. Our issues are intertwined with the political, social, economic, ethics, and science issues of today. These are major issues, critical and central to our quality of life and the sustainability and health of the planet Earth. The fact that the issues are bigger than us does not diminish our role, it only means we must adjust to a broader perspective. As natural resource professionals, our role is key. I trust that we are all committed to adjusting to that broad perspective and to serving those special needs of society. That is indeed a noble charge.

Central Hardwood Forests: Recent Trends in a Robust Resource

T.W. Birch, D.A. Gansner, and W.H. McWilliams[1]

Abstract: Re-inventories completed for each of four Central Hardwood States (Kentucky, Ohio, Pennsylvania, and West Virginia) show that forest area is increasing and stocking hit new highs; there is 27 percent more growing-stock volume than a decade ago. Large increases in volume have been recorded for all but the smallest diameter classes. Volume in trees 15 inches in diameter and larger is up 48 percent. There is more high quality hardwood sawtimber. The extent to which the resource is needed and utilized will depend on the same complex set of interrelated factors that it always has. These factors include trends in the tastes and preferences of the owners of forest land; technological changes in the production, marketing, and utilization of wood products and their substitutes; economic forces; attitudes of forest-land owners and other citizenry toward timber management and cutting; and attractiveness of local business climates. Only time will tell how it all works out. But for now, physical supplies of timber reveal a potential opportunity for significant expansion in wood use.

Forests of the Central Hardwood Region have been very good to us. They supported our pioneer forefathers in the development of a new Nation and fueled an industrial revolution, the likes of which we may never see again. They helped us through many a grueling skirmish, including two world wars. Through it all, they have never stopped yielding the kind of timber, water, recreation, and other treasures that contribute to one of the highest standards of living on earth. They did it while suffering through the constraining effects of wildfire, chestnut blight, gypsy moth, drought, air polution, diebacks, declines, and other pestilence.

You could argue, and with good reason, that our central hardwood forests are more vital to us now than ever before. Many of the region's well-stocked and maturing timber stands offer sorely needed opportunities for economic development. The wood-using industry has taken notice. Log exporters and domestic mill operators are looking to the resource for more of its high-quality oak, maple, cherry, walnut, ash, yellow-poplar, and other species. And more of the small and low-grade material that has had limited markets in the past is finding its way into pulpwood, strand board, and other products. But it's more than just timber and dollars. Several other concerns of the day—water quality, air polution, global climate change, biodiversity, the need to get away from it all—are linked with and have generated a growing interest in the "health" of the forest. It behooves us to keep close tabs on its condition and development.

---

[1] Resource Analysts with the Forest Inventory and Analysis Project, USDA Forest Service, Northeastern Forest Experiment Station, 5 Radnor Corporate Center, 100 Matsonford Rd., Suite 200, Radnor, PA 19087.

Fortunately, comprehensive forest inventories have been completed for four states: Kentucky 1988, Ohio 1991, Pennsylvania 1989, and West Virginia 1989 in the heart of central hardwoods country. Results give us a solid basis for evaluating the state of the resource (DiGiovanni 1990, Alerich 1990, 1993; Griffith et al. 1993).

FOREST AREA HOLDING ITS OWN

New inventories tell us that forest area has increased in Kentucky, Ohio, Pennsylvania, and West Virginia. There have been changes in land use from forest to urban and from forest to strip mines, but these losses have been more than offset by farm land returning to forest. Areas with the most dramatic increases were central Kentucky and northeastern and western Ohio. Nearly 50 million acres (52 percent) of the total land area in the four state region is now in forest; and in many counties, more than four-fifths of the land area is in forest (Figure 1). Counties with less than 20 percent of their land in forest are rare except in the Bluegrass Region of Kentucky and the corn belt of western Ohio. Virtually all of the forest is classified as timberland, that is, forest land capable of producing crops of industrial wood and not withdrawn from timber utilization. However, the area of reserved forest land has been increasing. In Pennsylvania it increased faster than the area reverting to forest—producing a net loss in timberland between inventories.

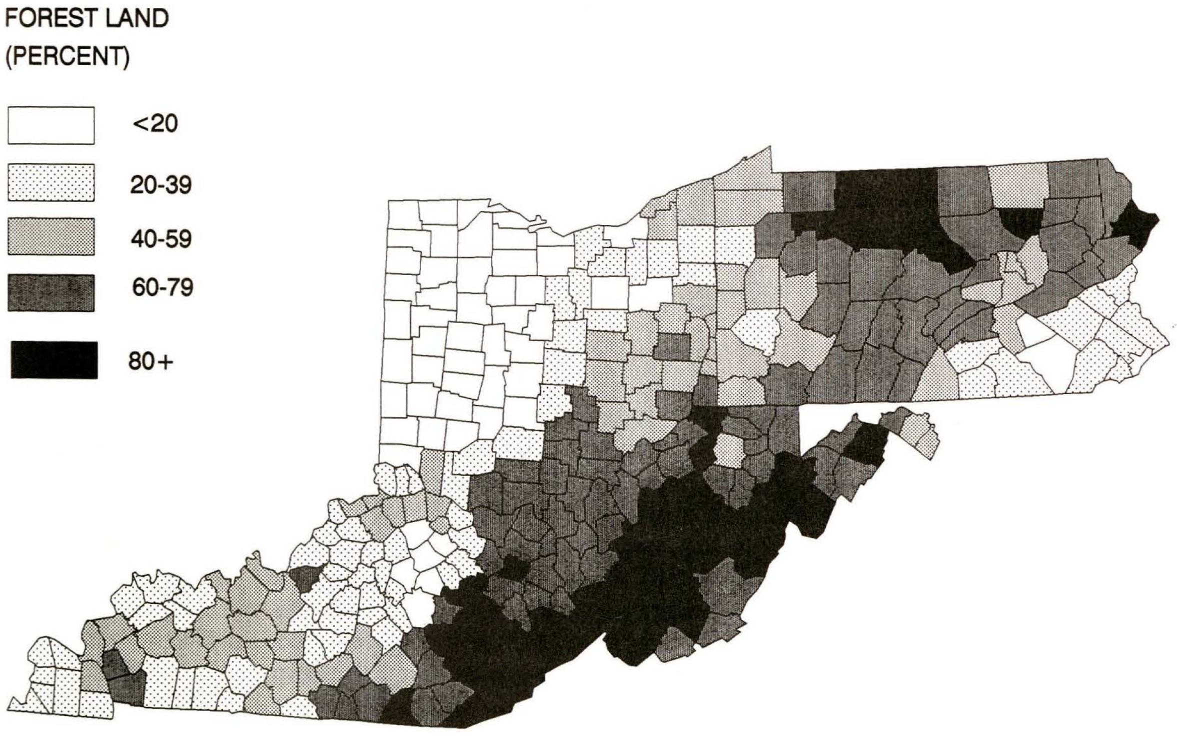


Figure 1.—Percent of land in forest, by county, Central Hardwood States.

HARDWOOD STOCKING HITS NEW HIGHS

The total volume of growing stock increased by more than 27 percent in the 12 to 14 years between inventories and now totals nearly 70 billion cubic feet. That translates to nearly 1,500 cubic feet per acre of timberland. A few counties now support more than 2,000 cubic feet of growing stock per acre (Figure 2).

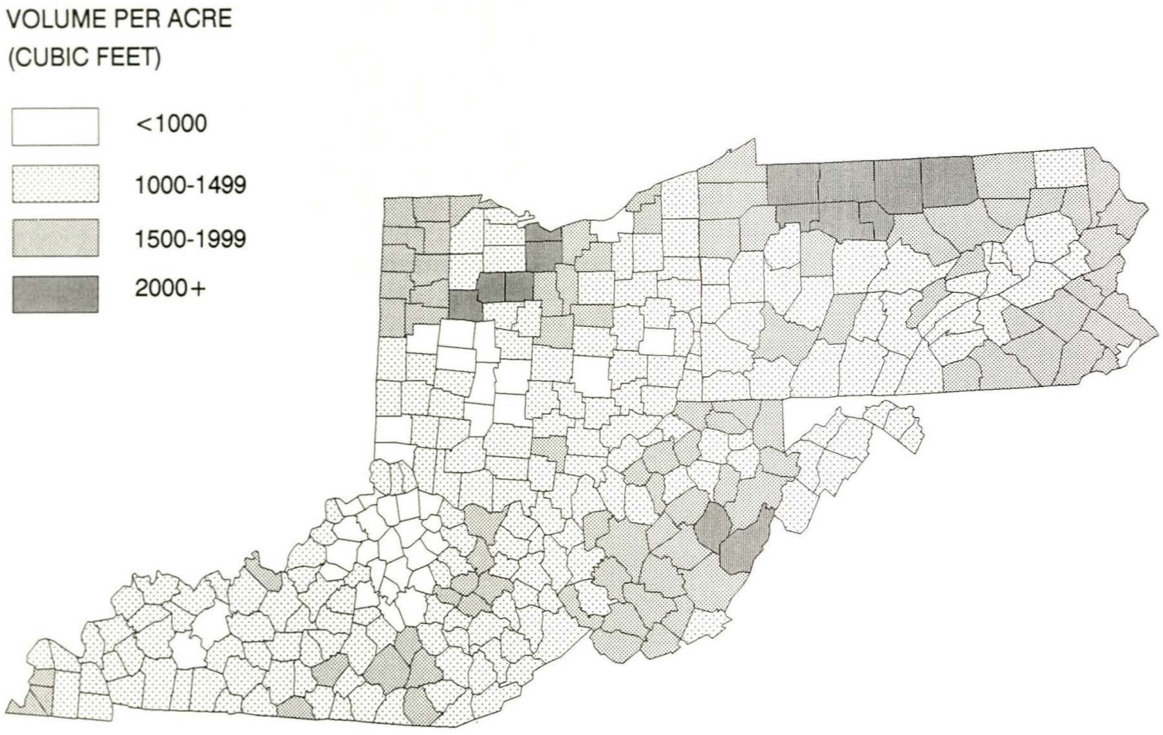


Figure 2.—Total growing-stock volume per acre of timberland, by county, Central Hardwood States.

Hardwood timber now averages 1,351 cubic feet per acre, a 25-percent increase in about 12 years. All major hardwood species shared in the volume gains (Figure 3). The oaks (white and red combined) still account for the largest share of the resource, but other species such as yellow-poplar, maple, and ash recorded impressive gains. Yellow-poplar volume increased by 54 percent to more than 6.6 billion cubic feet. Soft maple growing stock increased by 53 percent to 7.5 billion cubic feet.

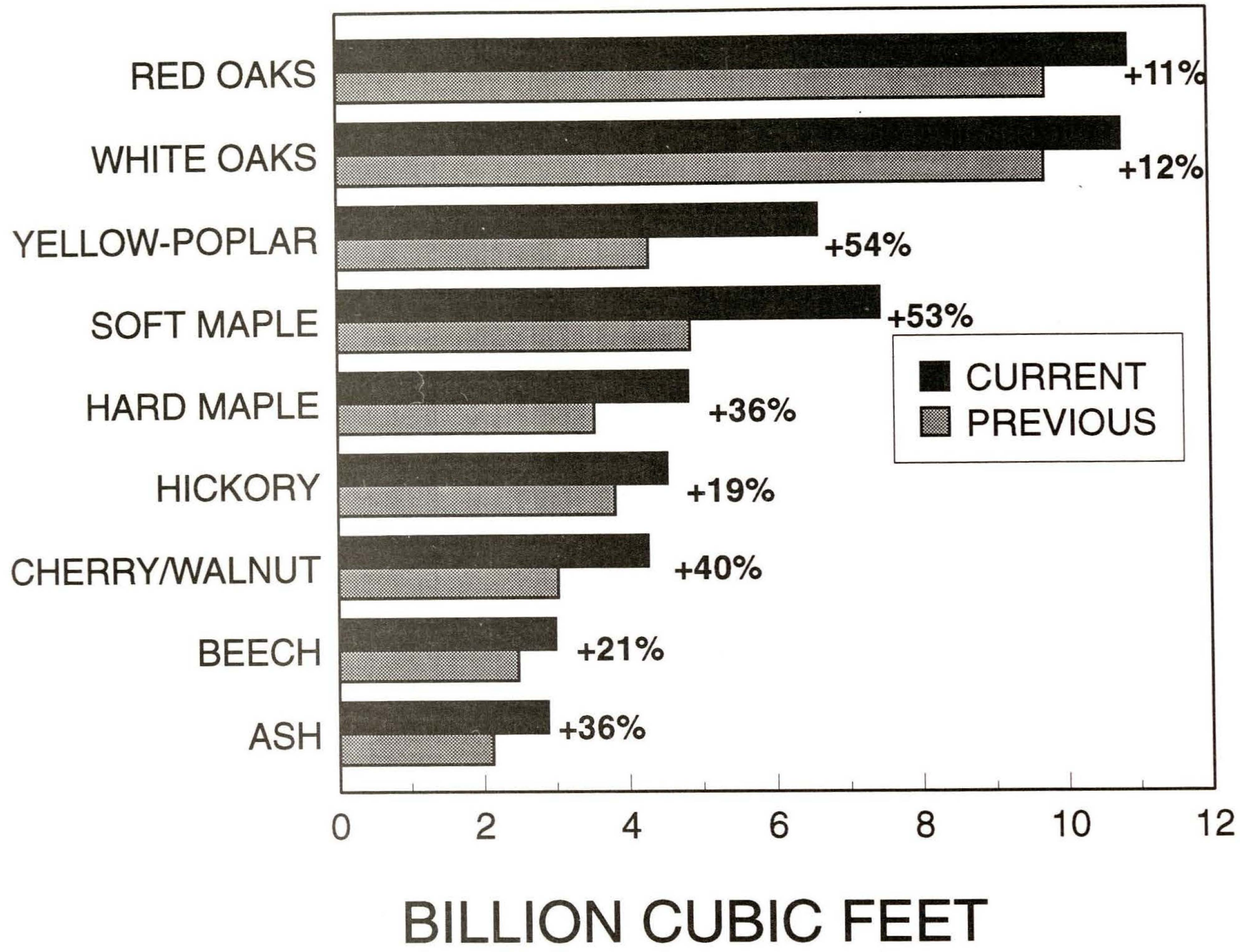


Figure 3.—Change in hardwood growing-stock volume by major species group, previous and most recent inventories, Central Hardwood States.

BIGGER TREES MEAN MORE HIGH-QUALITY TIMBER

The average size of hardwood timber is larger. Significant increases in volume were recorded for all but the smallest diameter classes (Figure 4). Volume in trees 15 inches and larger is up 48 percent (Figure 5). Not surprisingly, hardwood sawtimber volume also has increased substantialy and now averages nearly 4,000 board feet per acre.

Along with the increases in timber size have come increases in the volume of high-quality timber, though there is still a lot of lower grade material out there. Much of it is sound wood that is too small to grade out higher. Even so, the amount of sawtimber qualifying as log grade II or better is up significantly and now represents more than one-fourth of the total hardwood sawtimber inventory (Figure 6). Of course, quality varies by location, species, and size. For example, three-fourths of West Virginia's northern red oak sawtimber is in trees 16 inches and larger, and nearly half of that big red oak volume is log grade II or better material.

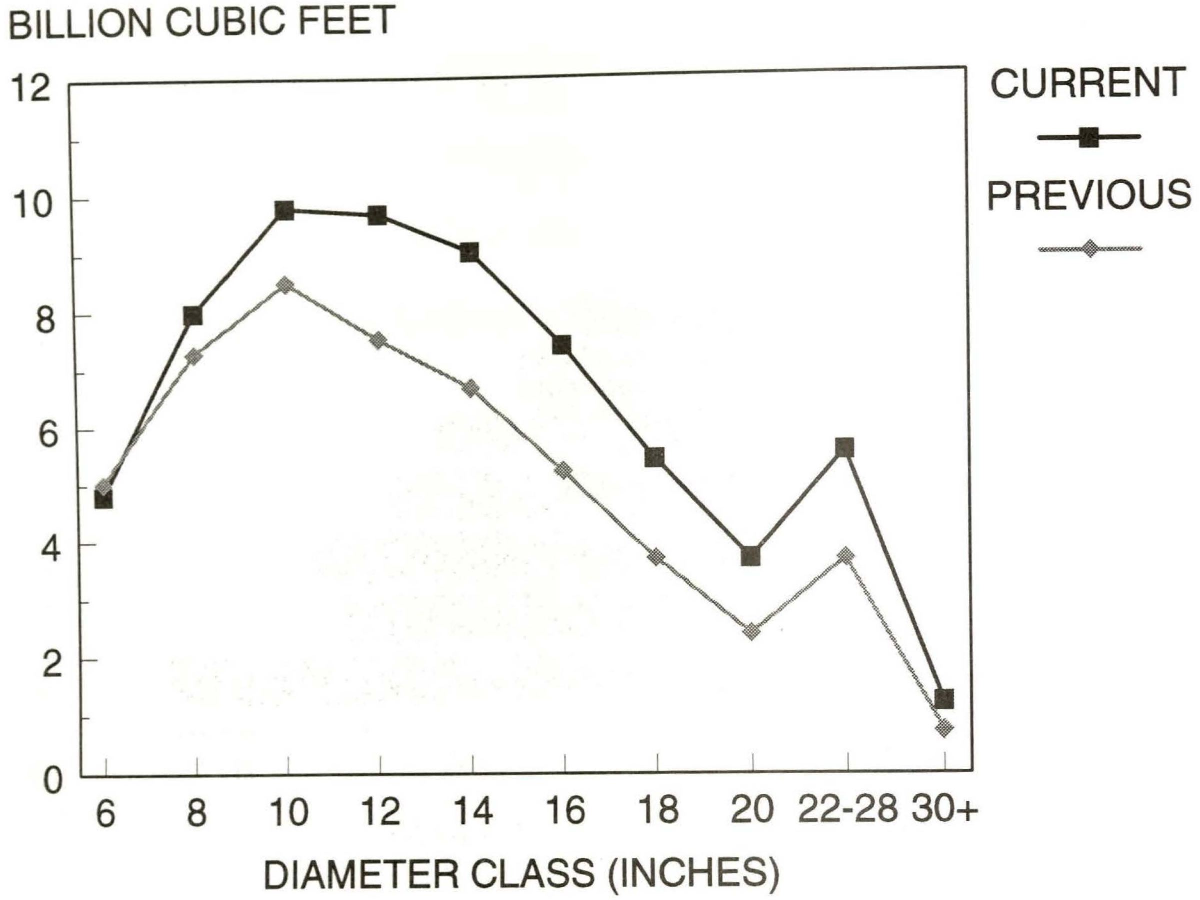


Figure 4.—Change in hardwood growing-stock volume, by DBH class, Central Hardwood States.

INVENTORIES CONTINUE TO BUILD

On average, hardwood growing-stock volume is dying at an annual rate of 0.5 percent (Table 1.) Growth put on by surviving trees, plus ingrowth of small trees into the inventory base, more than offsets this mortality. Average annual net growth amounts to 2.6 percent of the inventory; removals average 1.0 percent. Growth is thus more than 2 1/2 times removals, and hardwood growing-stock continues to increase at a rate of about 1.6 percent per year.

The balance between growth and removals varies among species. For example, soft maples, with relatively high growth rates and lower removal rates, have a large growth-to-removal ratio ratio. That is good news for users of red maple! But the gap is small for species with higher rates of use, such as white oaks, which also were hit hard by gypsy moth in Pennsylvania.

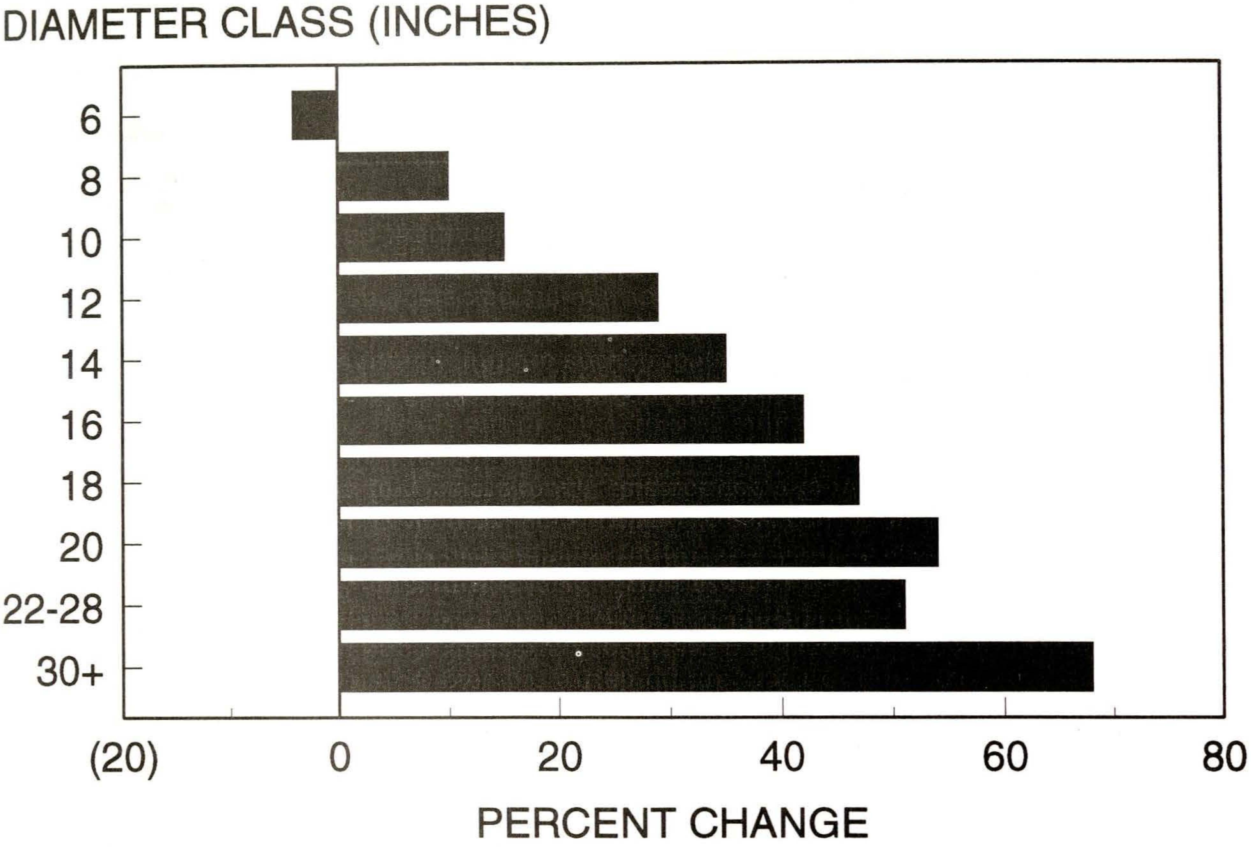


Figure 5.—Percent change in hardwood growing-stock volume between inventories, by DBH class, Central Hardwood States.

Table 1.—Average annual mortality, net growth, and removals of hardwood growing-stock volume as a percent of inventory, and growth-to-removals ratio, by species group

Species group	**Mortality**	**Net growth (NG)**	**Removals (R)**	**Ratio (NG/R)**
White oaks	0.6%	1.9%	1.4%	1.3
Red oaks	0.7	2.3	1.4	1.7
Yellow-poplar	0.2	3.5	0.9	3.8
Soft maple	0.3	3.2	0.7	4.6
Hard maple	0.4	2.8	0.8	3.3
Hickory	0.6	1.9	0.9	2.1
Ash	0.5	2.9	1.0	2.8
Sweetgum	0.2	3.0	2.1	1.4
Tupelo and blackgum	0.1	2.0	0.5	4.1
Beech	0.4	2.1	0.9	2.2
Cherry and walnut	0.4	3.2	1.2	2.7
All hardwoods	0.5	2.6	1.0	2.7

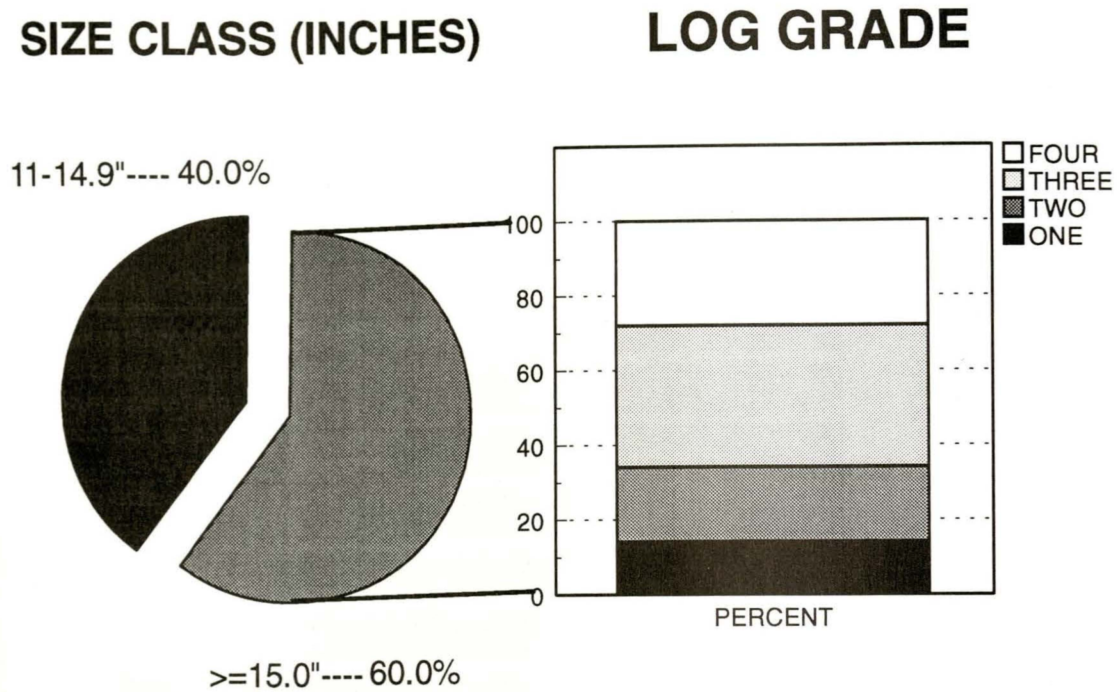


Figure 6.—Percentage of hardwood sawtimber volume by size class and log grade, three Central Hardwood States (Kentucky, Pennsylvania, and West Virginia).

PRIVATE FOREST-LAND OWNERS CONTROL THE RESOURCE

The social and economic characteristics of private forest-land owners and their objectives must be considered when looking at the central hardwood resource. In general, the individual private forest-land owner is younger, better educated, and has a higher income level than the owner of a decade ago (Birch 1992). The regional pattern describes a growing population of younger families moving into previously rural surroundings. However, in some portions of the region, population densities have declined between 1980 and 1990 (U.S. Bureau of Census 1991).

There has been a dramatic change in attitudes toward and experience with timber harvesting in the region. In 1976, in Kentucky and West Virginia, 30 percent of the private owners with 58 percent of the private timberland had harvested trees from their land (Birch 1992). A little over a decade later in 1989, 47 percent of the owners have harvesting experience and they control 66 percent of the private forest.

There is very little documentation of what type of management and cutting is taking place in the region's forests. In West Virginia, remeasured plot data indicates that 24 percent of that State's timberland had cutting disturbance between inventories (Birch et al. 1992). Four-fifths of the cutting took place on one-tenth of the timberland. About 8 percent of the basal area in live trees 5.0 inches and larger in d.b.h. was removed. The average annual cutting rate was about 0.6 percent per year. On 2 percent of the timberland, harvesting amounted to more than four-fifths of the origional basal area. But on 86 percent of the land, removals amounted to less than one-fifth of the basal area (Table 2). Clearly, partial cutting methods dominate in West Virginia and clearcutting is relatively rare.

Table 2.—Percentage of West Virginia timberland with cutting disturbance between inventories, by amount of origional basal area removed, 1977 and 1989

	Basal area removed					
State	**1-19**	**20-39**	**40-59**	**60-79**	**80+**	**Total**
West Virginia	10	6	4	2	2	24

Timber harvesting remains a laissez-faire activity throughout the region as economics, more than textbook silviculture determines the kind of cutting that takes place. Some landowners are practicing forestry and consider "cultural treatment" a prime reason for harvesting timber. Many have cleaned up defective trees while harvesting fuelwood to offset the high cost of energy. Some of that motivation has lessened as energy prices fell. However, "selective" cutting methods such as diameter-limit cutting dominate in designating what trees are cut. Few silviculturists condone this practice. Moreover, remeasured plot data indicate that much of the region's timberland remains overstocked with small and low-grade trees that could be thinned to improve species composition and quality. Also, many acres of mature forest are ready for harvest, and understocked forests that are not expected to reach acceptable levels of stocking in the near future could be regenerated. These actions would result in dramatic increases in production.

A STOREHOUSE OF ECONOMIC POTENTIAL

To get a better fix on timber supply potential, a special analysis of silvicultural cutting opportunities in oak-hickory forests of West Virginia was conducted. The study encompased 9.2 million acres of timberland. The effects of timber prices, ownership objectives, woodland accessibility, and other factors that influence the economic availability of timber were not considered in this analysis. The objective was simply to identify the acreage of timberland and yields of timber associated with recommended silvicultural cutting practices for the oak-hickory timber type.

The estimated cut from silviculturally sound thinning, regeneration, and harvest practices totals 100 million cords, or 60 times the current annual harvest of growing-stock volume from the State (Arner et al. 1991). On the stump, the tree conversion value of this material totals $2.4 billion. Also, the good housekeeping associated with all of this silviculture would improve timber productivity and quality. There is no denying that physical supplies of timber reveal a potential for significant expansion in wood use.

Such a rosy picture might tempt some to sit back, take credit, and rest on their laurels. But several not-so-subtle events do not allow complacency. Examples include the gypsy moth, which continues to plague the oak forests of the region, high deer numbers, and continued land fragmentation that may be threatening certain valuable plant and animal communities.

The extent to which the timber resource of the region is needed, managed, and utilized in the future will depend on a complex set of interrelated factors that operated in the past. These factors include trends in the tastes and preferences of the owners of forest land; technological changes in the production, marketing, and utilization of wood products and their substitutes; strength of the American dollar in the world market, trade deficits, inflation, and other economic forces; attitudes of forest-land owners and other citizenry toward timber harvesting and management; and attractiveness of local business climates and living environments. Only time will tell how this all works out. In the meantime, some watchful monitoring of the resource backed by good stewardship will help guarantee a continued flow of the products and services we have come to expect from the forests of the region.

LITERATURE CITED

Alerich, C.L. 1990. Forest statistics for Kentucky—1975 and 1988. USDA For. Serv. Resour. Bull. NE-117. 295 p.

Alerich, C.L. 1993. Forest statistics for Pennsylvania—1978 and 1989. USDA For. Serv. Resour. Bull. NE-126. 244 p.

Arner, S.L., D.A. Gansner, M.E. Dale, and H.C. Smith. 1991. Silvicultural cutting opportunities in oak-hickory forests of West Virginia. p. 360-372 In: 8th central hardwood forest confernece USDA For. Serv. Gen. Tech. Rep. NE-148.

Birch, T.W., D.A. Gansner, S.L. Arner, and R.H. Widmann. 1992. Cutting activity on West Virginia timberlands. North. J. Appl. For. 9(4):146-148.

Birch, T.W. 1992. Land ownership and harvesting trends in eastern forests. p. 143-157 In: Twentieth annual hardwood symposium of the Hardwood Research Council, June 1-3, Cashiers, NC. Hardwood Res. Counc., Cashiers, NC.

DiGiovanni D.M. 1990. Forest statistics for West Virginia—1975 and 1989. USDA For. Serv. Resour. Bull. NE-114. 172 p.

Griffith, D.M., D.M. DiGiovanni, T.L. Witzel, and E.H. Wharton. 1993. Forest Statistics of Ohio, 1991. USDA For. Serv. Resour. Bull. Northeast. For. Exp. Stn., Radnor, PA. In press.

U.S. Department of Commerce, Bureau of Census. 1991. 1990 Census of population. U.S. Dep. Commer. Bur. Census, Washington, DC.

Growth and Shifts in Eastern Hardwood Lumber Production

William G. Luppold and Gilbert P. Dempsey[1]

Abstract: An analysis of recent trends in eastern U.S. hardwood lumber production indicates that total output increased sharply between 1977 and 1991. The increase, however, was much more pronounced in the East's northern tier of states than in the southern. This paper first examines recent hardwood lumber usage trends and historic hardwood lumber production trends. Changes in hardwood lumber production over the last 15 years are then related to changes in national hardwood lumber demand and regional differences in timber attributes.

INTRODUCTION

The demand for eastern U.S. hardwood lumber products has changed constantly over the last 15 years. Perhaps the most significant change has been the increased demand for higher quality lumber by the millwork and export markets (Table 1). The species that appear to be the most desired by these markets are the select red and white oaks, ash, cherry, and, more recently, hard maple and yellow-poplar (Tables 1 and 2). Some other important changes shown in Table 1 are: (1) the increased use of hardwood lumber in the pallet, kitchen cabinet, and flooring industries; and (2) the decrease in lumber use by the household furniture industry.

The growth in hardwood lumber demand and the changes in the industries that use hardwood lumber affect lumber prices in general, and especially the prices of particular species. Changes in lumber price in turn affect hardwood lumber production. The remainder of this paper will examine historic changes in hardwood lumber production, and then relate changes in hardwood lumber production over the last 15 years to changes in hardwood lumber demand and regional differences in timber attributes.

HARDWOOD LUMBER PRODUCTION TRENDS

Because of errors in official estimates of hardwood lumber production (Cardellichio and Binkley 1984, Luppold and Dempsey 1989), hardwood lumber production volumes used in this paper are based on procedures developed by Luppold and Dempsey (1989) and Dempsey and Luppold (in review). These procedures utilized information developed from U.S. Department of Agriculture, Forest Service Timber Product Output Studies, state severance tax records, and periodic state surveys of hardwood production. All data concerning hardwood inventories were developed from documents by the USDA Forest Service (1982) and Waddell, Oswald, and Powell (1989).

---

[1] Project Leader and Principal Economist, respectively, USDA, Forest Service, Northeastern Forest Experiment Station, Princeton, WV 24740.

Table 1.—Hardwood lumber consumption by major U.S. industries and exports, 1977 and 1991, and the species most commonly demanded (in million board feet)

Industry	1977	1991	Species used
Furniture group			
Wood household*	2,330	2,060	Red oak
Upholstered	254	286	Mixed hardwoods
Commercial	221	399	Oak/cherry/walnut
Construction products			
Millwork	372	627	Red oak
Kitchen cabinets	358	573	Red oak
Flooring	304	529	Red oak
Industrial products			
Pallets	2,627	4,624	Mixed hardwoods
Railroad crossties	1,000	636	Mixed hardwoods
Exports	240	850	Red & white oak

*Wood household furniture figures include hardwood lumber use by the dimension industry.

Source: Dempsey and Luppold 1992. Periodic state surveys of hardwood lumber production. All data concerning hardwood timber inventories were developed from documents by the USDA Forest Service (1982) and Waddell, Oswald and Powell (1989).

Table 2.—Eastern U.S. hardwood lumber exports to major markets, 1981 and 1991, and the species most commonly demanded (in thousand board feet)

Major market	1981	1991	Species used
Asia			
Japan	7,769	114,346	Ash/poplar/oaks
Taiwan	9,855	85,744	Red oak
Korea	2,524	19,406	Hard maple
Others	1,256	31,228	Oaks
Northern Europe			
Belgium	22,572	56,085	White oak
Germany	20,897	39,506	White oak
Netherlands	22,845	20,438	White oak
United Kingdom	5,108	42,368	White oak
Others	571	3,849	White oak
Southern Europe			
France	13,150	21,915	Red oak, cherry
Italy	12,661	70,432	Poplar
Spain	2,638	35,119	White oak
Others	160	8,451	White oak
North America			
Canada	195,325	197,098	Red oak
Mexico	9,963	41,837	Red oak

Source: Luppold and Thomas (1991).

An examination of Figure 1 indicates that hardwood lumber production is cyclical, with the periodicity of the cycle (from top to top) declining from 7 years to 5 over the 27-year period. Much of the cyclical behavior of hardwood lumber production can be related to changes in the overall economy and the impact of these changes on hardwood lumber price. Another trend evident in Figure 1 is the upward movement of the cycle since 1975. This upward movement appears to be a direct result of growth in demand exhibited in Table 1.

Another trend shown in Figure 1 is the gradual shift in hardwood lumber production from the southern regions to the northern regions. Between 1965 and 1977, this shift exhibits itself as small increases in production in northern regions and a gradual production decrease in the southern regions. Production in all eastern regions has increased since 1977 with larger increases in northern regions and smaller increases in the southern regions.

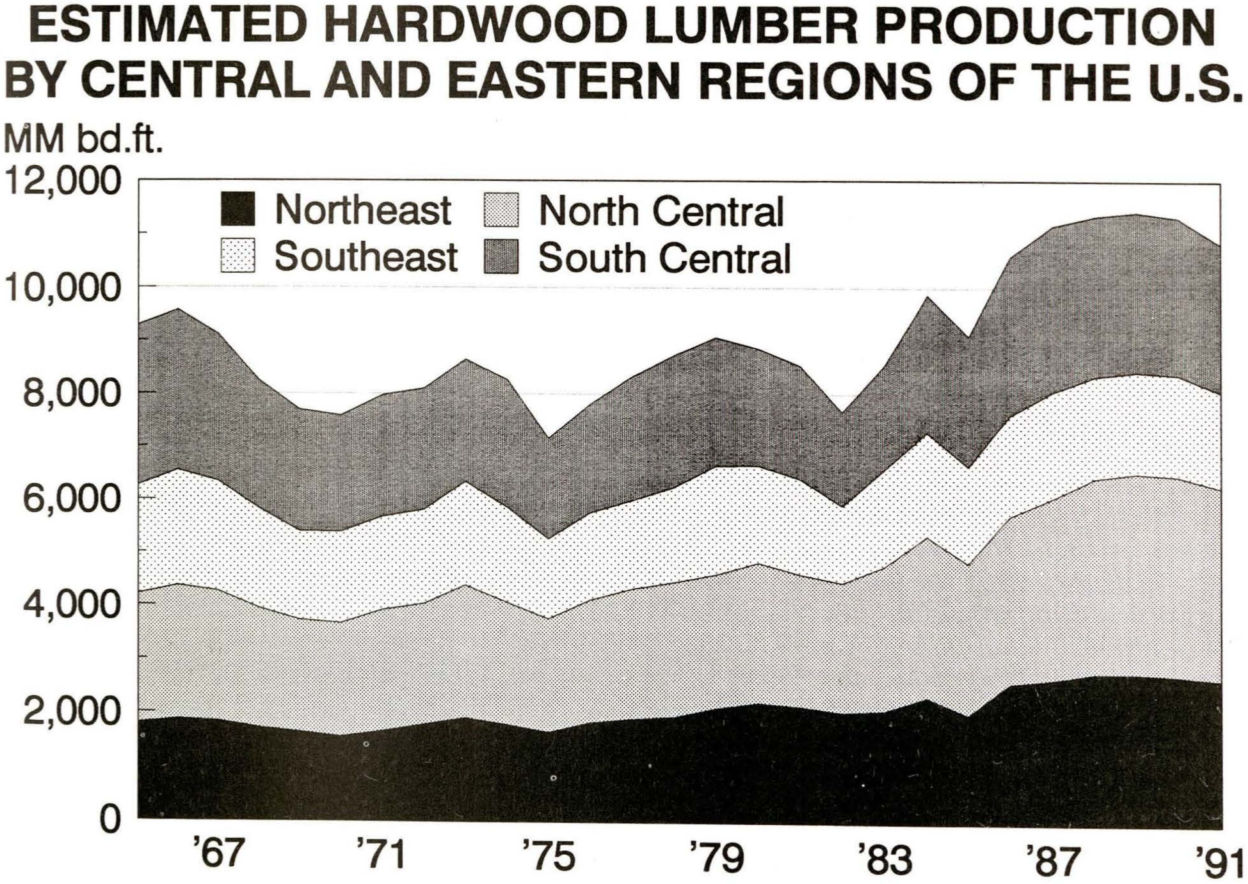


Figure 1.—Estimated hardwood lumber production by Central and Eastern Regions of the U.S.

An alternative way of looking at the shifts in regional production over the last 15 years is presented in Table 3. The information in this table contrasts actual shifts in regional production in 1991 against the shifts expected if all regions grew at the national rate. Although production in all four central and eastern regions increased over this 15-year period, the northern regions grew at a much faster rate than the southern regions and the central regions grew faster than their eastern counterparts.

Table 3.—Relative change in eastern U.S. hardwood lumber production, by region, 1977 and 1991

Region	**Lumber production (MM BF) 1977**	**1991**	**Expected change (EC)**	**Actual change (AC)**	**Difference (AC - EC)**
Northeast[a]	1,894	2,657	573.4	763	189.6
North central[b]	2,430	3,602	735.6	1,172	436.4
Southeast[c]	1,658	1,803	501.9	145	-356.9
South central[d]	2,339	2,778	708.0	439	-269.0

[a] Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and West Virginia.

[b] Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, and South Dakota.

[c] Florida, Georgia, North Carolina, South Carolina, and Virginia.

[d] Alabama, Arkansas, Louisiana, Mississippi, Oklahoma, Tennessee, and Texas.

Perhaps the best explanation for the shifts in regional production is the increased demand for higher grade lumber from the select sawtimber species, combined with the higher proportion of these species in the northern regions (Table 4). The proportion of select species in the northern regions is twice the percentage of their southern counterparts. Another contributing factor is the higher total volume of hardwood sawtimber in the north-central as compared with the south-central regions. Although the northern regions appear to have ample supplies of the select species, their other attributes, such as average timber diameter and ratio of private to public land ownership, are less conducive to lumber production.

Table 4.—Attributes of the eastern U.S. hardwood timber resource, by region, 1987

Region	Total volume (billion bdf)	Select species (percent)	Average diameter (inches)	Ratio of private to public ownership
Northeast[a]	171.7	42.7	16.5	4.3
North central[b]	198.5	38.1	16.9	4.2
Southeast[c]	183.4	18.5	17.8	7.4
South central[d]	161.9	21.2	17.2	7.2

[a] Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and West Virginia.

[b] Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, and South Dakota.

[c] Florida, Georgia, North Carolina, South Carolina, and Virginia.

[d] Alabama, Arkansas, Louisiana, Mississippi, Oklahoma, Tennessee, and Texas.

One of the most interesting aspects of Table 4 is that timber diameter is negatively correlated with the percentage of select species. The cause of this correlation is due probably to a more rapid harvest of the select species, the slower growth of timber in the northern areas, and the slower growth of many of the select species.

Even though the demand for select species has encouraged greater lumber production in the northern regions, the existence of a growing pallet market in these regions also helped facilitate this growth in production. Because the density of population and heavy industry are both higher in the north than in the south, pallet production and the subsequent use of hardwood lumber by the pallet industry is greater in the north. The existence of the pallet industry provides the grade lumber industry an outlet for log hearts and loggers a market for low-grade logs. The synergistic relationship between pallet production and high-grade lumber production probably allowed lumber output in the northern region to be higher than it would have been in the absence of the pallet industry.

One factor that may be affecting hardwood lumber production in the south is the increased demand for lower grade timber resources in this region by the pulp and paper industry. There is strong, but not fully substantiated, evidence that hardwood timber cut by the pulp and paper industry is exceeding growth in some areas of the south. This strong demand may be hindering log procurement for some southern hardwood sawmills that utilize lower grade logs for the production of pallets and railroad crossties.

FUTURE CHANGES IN HARDWOOD LUMBER PRODUCTION

As stated earlier, hardwood lumber demand affects hardwood lumber production through price. Therefore, any demand factor that affects the price of hardwood lumber in general, or the price of a specific species, will have a corresponding impact on hardwood lumber production. In the last 15 years, lumber production has been very much influenced by increased hardwood lumber exports and by the increased demand for hardwood lumber by industries producing products for the construction market. However, the changes that occurred over the last 15 years may only slightly resemble the changes that may occur over the next 15 years.

Some demand factors that will affect hardwood lumber production in a positive manner are: the continued export demand resulting from the weakened dollar, increased demand for railroad ties, increased development and sales of prefinished hardwood flooring systems, continued remodeling and expansion of kitchens, and the increased desire of homeowners to purchase hardwood furniture and millwork.

Factors that will affect hardwood lumber production in a negative manner are: the reduced production of single-use pallets because of disposal problems, increased imports of wood furniture—with imports from Mexico increasing, and the reduced demand for millwork by the commercial construction industry. One other factor that could hinder hardwood production in the north is the increased regulation on nonprivate lands. However, hardwood lumber production in the south may be equally hindered by increased timber demands by the pulp and paper industry.

Although hardwood lumber production may increase in the 1990's, it will probably not increase at either the regional or national rates experienced over the last 15 years.

LITERATURE CITED

Cardellichio, P.A. and C.S. Binkley. 1984. Hardwood lumber demand in the United States: 1950 to 1980. For. Prod. J. 34(2): 15-22.

Dempsey, G.P. and W.G. Luppold. 1992. The state of hardwood lumber markets. North. Logger & Timber Proc. 40(10): 22-24.

Dempsey, G.P. and W.G. Luppold. In review. An historical examination of regional hardwood lumber production and sawtimber availability. North. J. Appl. For.

Luppold, W.G. and G.P. Dempsey. 1989. New estimates of central and eastern U.S. hardwood lumber production. North. J. Appl. For. 6(3): 120-123.

Luppold, W.G. and R.E. Thomas. 1991. New estimates of central and eastern U.S. hardwood lumber exports to Europe and Asia. USDA Forest Service NE-652, 22 p.

USDA Forest Service. 1982. An analysis of the timber situation in the U.S., 1952-2030. For. Resour. Rep. No. 23. Washington, DC.

Waddell, K.D., D.D. Oswald and D.S. Powell. 1989. Forest statistics of the United States, 1987. USDA Forest Service PNW-RB-168. 106 p.

Oak Silviculture, Management, and Defoliation Effects in France and Germany

Kurt W. Gottschalk[1]

Abstract: A study tour of four areas of France and Germany (two in each country) was conducted to examine oak silvicultural and managerial practices and the influence of insect defoliators on the ecology and management of oak forests. The French and German situations may provide useful information for managing oak forests and gypsy moth in the United States, especially the central hardwood region.

Both France and Germany manage their oak stands for sawtimber and veneer production, the latter as the final and most valuable product. Frequent intermediate treatments and thinnings provide lower quality products and sawtimber throughout the rotation. Even-age systems are used almost exclusively with rotation ages varying by area (120 to 300+ years). Most regeneration is by natural regeneration using shelterwood cutting. In many areas, seed collection and direct seeding of oaks are done under the shelterwood system. Planting is used in areas of poor seed production due to frosts. Competition control, a major expense during the regeneration phase, is accomplished by a combination of chemical and mechanical (manual) methods. Many areas in France and some in Germany are in the process of converting oak stands from coppice with standards to high forests. The major species present are sessile oak, *Quercus petraea* Liebl., pedunculate (or English) oak, *Q. robur* Erh., and, in the drier areas of France, pubescent oak, *Q. pubescens* W. In both France and Germany, northern red oak, *Q. rubra* L., has been widely planted in some areas.

Outbreaks of insect defoliators occur in both France and Germany, but are closely linked to site and climatic conditions. Major defoliators are gypsy moth, *Lymantria dispar* L.; oak leafroller, *Tortrix viridana* L.; and winter moth, *Operopthera brumata* L.; some areas also have defoliation from large winter inchworm, *Hibernia defoliaria*, and common wanderer moth, *Thaumetopoa processionea*. The major effects of defoliation in oak stands are, in order of importance, loss of seed (mast) crops, growth loss, and tree mortality. Loss of seed crops is critical in many areas and mortality increases in importance on drier sites. Poor silviculture also contributes to increased mortality in stands due to lowered tree vigor and poorer crowns.

INTRODUCTION

During September and October of 1988, I conducted a study tour of four oak-forest areas in France and Germany: 1) the oak forests in the foothills (Lorraine Plateau) west of the Vosges Mountains in northeastern France; 2) the oak forests in the low plateaus around the Loire River Valley in central France; 3) the Spessart oak-forest area and areas adjacent to Main River Valley east of Würzburg in the northern portion (Upper Franken) of the State of Bavaria; and 4) the upper Rhine Valley oak forests and oak forests in the foothills of the Black Forest near Freiburg in the State of Baden-Württemberg. The purpose of the trip was to study oak silviculture and management and the impacts of oak defoliators on ecology and management of these forests. The situations and experience of the French and Germans in these areas may prove helpful for oak management and gypsy moth in the United States.

---

[1] USDA Forest Service, Northeastern Forest Experiment Station, 180 Canfield St., Morgantown, WV 26505-3101.

The areas visited are in the productive oak forests of central and northern Europe and are not part of the Mediterranean or sub-Mediterranean zones. The two major species of oak that are native to and managed for in this region are English oak, *Quercus robur* Erh., also known as pedunculate oak (*Q. pedunculata*), and sessile oak, *Q. petraea* (Matt.) Liebl., also known as Durmast oak. Both species are in the white oak group. There are no native red oaks outside in Europe. Pedunculate (the name used in continental Europe) and sessile oak are similar and at one time were considered varieties of the same species. Recent work has shown that there are genetic, morphological, and ecological differences. At the INRA-CNRF Station de Sylviculture et de Production in Nancy, France, a multivariate analysis technique for separating the two species based on leaf morphology shows that less than 5 percent of the trees are hybrids. Current work is looking at isozyme analysis and an Italian lab is doing DNA electrophoresis. There are several major ecological differences between the two species: pedunculate oak is not as drought tolerant and grows on wetter sites, requires a better mineral nutrition, begins growing later in the spring and is less susceptible to late frosts, is more susceptible to the powdery mildew fungus, *Microsphaera alphitoides* (Grif. and Maubl.), and usually grows in valleys where conditions are humid and sites less well drained. Pedunculate oak also is the major species associated with oak decline, which usually occurs where this species was introduced (planted offsite). Pedunculate oak also has a higher mortality rate due to drought and defoliation than sessile oak, especially on drier sites. The two species often grow in mixed stands or forest areas, but sessile oak usually is predominant on all but the moistest sites.

FRANCE

France has 13.7 million hectares (ha) of forests which occupy 25 percent of the total land area and represent 40 percent of the European Economic Community's (EEC) forests (Anonymous 1984). The forest ownership is 12 percent state, 17 percent community, and 71 percent private. The state and community forests are managed by the National Forest Service. The private forests have more than 3 million owners; 25 percent hold fewer than 4 ha, 35 percent hold 4 to 25 ha, and 40 percent hold more than 25 ha. A third of all private forests are part of a farm. Of the country's forests, 30 percent are classified as unproductive or protection forests for water and soil (much of this is in the Mediterranean area), another 30 percent is coppice or coppice with standards forest that provides primarily firewood and pulpwood with some higher quality products, and 40 percent is in high (or seed origin) forests that provide pulpwood, sawtimber, and veneer. France's wood needs require 20 percent to be imported at a deficit cost of 14.1 billion francs ($2.27 billion) per year.

Conifers comprise 34 percent of the forested area and hardwoods 66 percent. Of the hardwood forest, oak types comprise 40 percent, common or European beech (*Fagus sylvatica* L.) 12 percent, hornbeam (*Carpinus betulus* L.) 4 percent and other hardwoods 10 percent. Oak (eight native species) occurs in five major forest types: pedunculate/sessile oak type; oak and beech mixed type, which includes the two major oak species mixed with beech; beech and oak mixed type, which is beech forest with the two major oaks mixed in; sub-Mediterranean oak type, which is pubescent oak (*Q. pubescens* W.), sweet chestnut (*Castanea sativa* L.), and beech mixed; and the Mediterranean oak type, which is holly-oak or holm-oak (*Q. ilex*, an evergreen oak), pubescent oak, European black or Austrian pine (*Pinus nigra* var. *nigra*), maritime black pine (*P. nigra* var. *maritima*), and Alep pine (*P. halepensis*).

Other oaks that occur in dry areas of southern and western France are cork oak (*Q. suber*) and tauzin oak (*Q. pyrenaica*). Sessile oak is by far the most common oak in the first three types, in which most of the quality oak veneer is grown. My visit was limited to the pedunculate/sessile oak and beech and oak mixed types and to state-managed forests. The two areas visited in France were the Lorraine Region in the northeast part of the country and the Loire Region in the center of the country.

Lorraine Region

Lorraine is one of the more heavily forested areas of France (40 percent of 2.2 million ha). These 865,800 ha of forest are predominately publicly owned (26 percent state and 41 percent community). It is first in France in the production of hardwood and second in the production of conifers. The area produces 12 percent of France's round logs and 12 percent of its lumber. Oak forests comprise 32 percent of the region, beech forests 29 percent, other hardwoods 11 percent, and conifers 28 percent. Coppice with standards occurs on 26 percent of the state forests and 57 percent of the community forests. The regional harvest from 1973 to 1982 averaged 6.4 m^3/ha/yr worth 1,310 fr/ha/yr on state forests and 4.2 m^3/ha/yr worth 790 fr/ha/yr on community forests. The area is composed primarily of the Lorraine Plateau with some portions of the Vosges Mountains. The Lorraine Plateau has a steadily increasing elevation that leads up to the Vosges Mountains. Composed of limestone, it is 200 to 400 m in elevation, with fertile, calcareous soils and oak and beech forests. It gives way to the pre-Vosgian hills, composed primarily of sandstone, at an elevation of about 300 to 400 m, with frequent silts and extensive beech and oak forests. Climate is continental with some oceanic influences; average annual temperature is 9.4°C and average annual precipitation is 700 mm over 170 days. This area is subject to late frosts in May.

Two forests were visited in the region. Champenoux State Forest is a 459-ha predominately oak forest just north of Nancy. Sessile oak is the principal species and is found on the plateau and slopes. Pedunculate oak is found in the moist bottoms. Other species include beech, hornbeam, littleleaf linden (*Tilia cordata* M.), European ash (*Fraxinus excelsior* L.), and various minor fruit species (wild or bird cherry, *Prunus avium* L.; serviceberry, *Amelanchier* spp.; European mountainash, *Sorbus aucuparia* L.). The forest was once a hunting preserve and managed in coppice with standards. Conversion to high forest began in 1826. Average production is 4.3 to 5.0 m^3/ha/yr. The forest is divided into 62 stands of 6 to 8 ha each. Haye State Forest, northwest of Nancy, is predominantly beech with some sessile and pedunculate oak. Some pubescent oak occurs with poor beech on the xeric soils on the southern slopes that fall off the plateau. Moist bottoms contain pedunculate oak, European ash, linden, sycamore maple (*Acer pseudoplatanus* L.), buckeye (*Aesculus* spp.), and fruit species. As the soils become deeper, productivity increases. At soil depths greater than 1 m, pedunculate oak is mixed with beech; at shallower soils, sessile oak is mixed with beech. Natural regeneration of beech is easily obtained.

Loire Region

The Loire Region is only about 10 percent forested. It is a low plateau that is bisected by the Loire River and its many tributaries. Agriculture, especially vineyards, is important in the region. Climate is moderate but varies within the region. In Blois State Forest along the Loire River, the elevation is 89 to 144 m with many small valleys assuring good drainage. Average annual temperature is 10.9°C with monthly averages of 2.8 to 19.4°C. Average annual precipitation is 655 mm over 169 days and is distributed evenly throughout the year. Soils are primarily clay and flint based, with some limestone in the north and a layer of silt in the east. Sessile oak is 97.5 percent of the forest. Average production from 1949 to 1978 was 4.8 m^3/ha/yr worth 169 fr/ha/yr. From 1979 to 1987, the average harvest was 5.7 m^3/ha/yr worth 2,100 fr/ha/yr. The Bourges District Office (Soudrain and Thoux Forests) is in the Cher River Valley (tributary of Loire). Its geology is limestone giving calcareous soils that are shallow but good for forests when deep enough. Soil depths of 50 cm are adequate and depths of 1 m or more are perfect. Climate is more sub-Mediterranean, warmer and drier. Average annual precipitation is still 600 to 700 mm, but April and July have only 14 mm each and are very dry.

Blois State Forest, the first area visited in the region, is 2,753 ha of predominately sessile oak. In the northern portion of the forest, 10 percent is pedunculate oak, beech and hornbeam also are found. The climate is favorable for the production of acorns, with good crops occurring every 2 to

5 years, but poor for the production of beech with little or no seed production. In fact, beech is now planted in the area. The forest is a relic of a vast forest that was cleared during the Middle Ages. It was owned by the Count of Blois and was passed to Louis d'Orlêans in 1391 and to the King of France, Louis XII in 1498. Since 1791, the forest has been a National Forest. The area formerly was mixed beech and oak forest, but past management practices eliminated the beech. The last cutting of coppice was in 1686, the area has been managed as high forest since that time. Boulogne State Forest, near Blois, has a similar history of long ownership by royalty and the state.

In the Bourges District Office, two forests were visited. The 600 ha Soudrain State Forest was owned by a religious group. During the French Revolution (1789), all of the trees in the forest were cut. As a result, most of the stands are now 180 to 200 years old. Soils are 50 to 60 cm deep and affected by drought. There also has been with defoliation in the area. Thoux State Forest, 900 to 1,000 ha, was privately owned until 1960. It was managed as coppice with standards. The government bought it in 1973 after a gypsy moth outbreak had killed many trees. The soil is poorer here and very shallow. Pubescent oak occurs on shallower soils and pedunculate oak and sessile oak on deeper soils. Coppice is hornbeam and hedge maple (*Acer campestre* L.).

Oak Silviculture and Management

A key component of silviculture and management in France, is an extensive ecological site classification program based primarily on soils and natural vegetation. Since France has mostly natural forests and plantations of exotic species are rare, classification is possible using natural vegetation. France has divided into 100 natural regions on the basis of geology, topography, and climate. A typology is produced within each region. The product is a catalog of sites. The typology is developed by sampling forest types using transects with plots at 100-m intervals if site changes. At each point, vegetation is listed and complete soil and stand descriptions are prepared. Following the field work, a factorial analysis on understory vegetation is done. This is followed by analyzing soils with vegetation for homogeneity and then creating homogeneous units based on those two characteristics. After the typology is established, the productivity of each type is studied.

The ecological site classification system is used to determine what species should be managed, the rotation length, the thinning interval, and the expected productivity of the site. For example, on Haye State Forest, understory vegetation and soil depths changed with increasing productivity. On the steep slopes at the break of the plateau, soils are very shallow, calcareous, and nonproductive, and understory vegetation is *Cornus*, *Corylus*, *Lonicera*, *Crataegus*, *Ribes*, and *Hedera helix*. As you move to the top of the plateau and add 10 to 15 cm of clay loam on top of the calcareous soil, productivity is now 5 m^3/ha/yr, there are no longer any woody shrubs, and understory vegetation is grass, *Asperillum*, *Macullerlis*, legumes, *Hedera helix*, *Vinca*, and *Rosea*. Moving along the plateau to clay loam soils that are 25 to 40 cm deep, the understory is now grass and fern with grass being characteristic. Finally, as you reach the most productive sites (7.6 m^3/ha/yr) with a soil depth greater than 1 m, the understory vegetation is *Rubus*, *Oxalis*, and *Euphorbia*.

The management goal of state and community oak forests is a sustained yield of maximum value. This goal is met by producing high-quality timber using long rotations. Toward that goal, the Office National des Forêts (ONF, French Forest Service) began to convert coppice and coppice with standards stands to high forests in 1827. Not all of these stands will be converted as some areas will continue to be managed for fuelwood and/or for game habitat (Figure 1). The long rotations, 120 to 160 years for pedunculate oak and 150 to 210 years for sessile oak (some areas would like to extend the rotation to 240 years), also provide a great diversity of products and amenities. The goal is to produce high-quality oaks for veneer due to the high premium that veneer brings in Europe. Average prices in France for sales in October 1979 were: dbh 50 cm and more, 850 fr/m^3 ($775/M bf); dbh 30 to 45 cm, 279 fr/m^3 ($254/M bf); and dbh 25 cm and less, 18.5 fr/m^3 ($7.59/cord) (Oswald 1982).

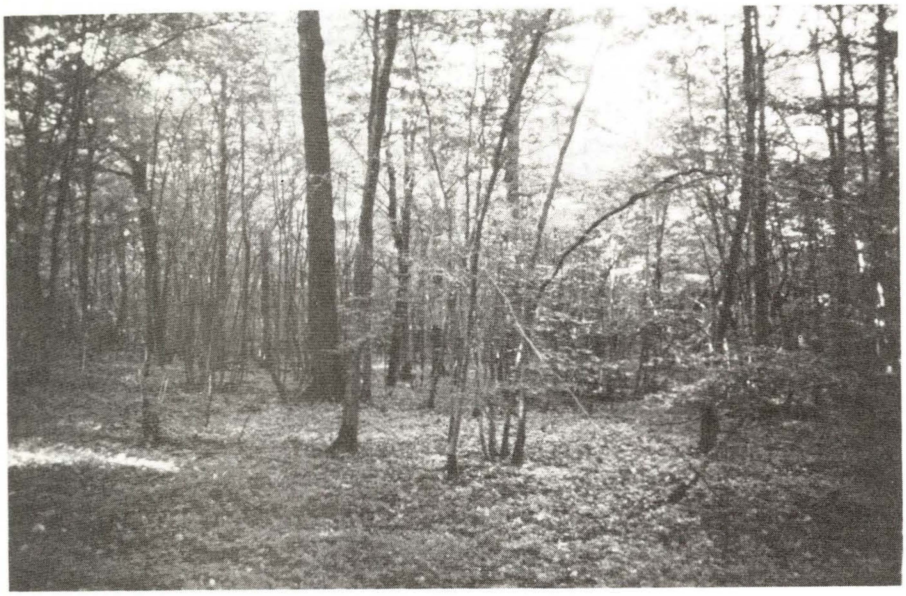


Figure 1.—Typical coppice with standards stand located on the Champenoux State Forest. At the time of the last inventory in 1975, the oak standards were 190 to 200 years old, had 127 trees/ha, 19.85 m^2/ha basal area, average d.b.h. of 140 cm, and average height of 23.2 m. The coppice was 75 percent hornbeam and 25 percent linden with several other species. It was 58 years old, had 1,375 trees/ha, 8.58 m^2/ha basal area, average d.b.h. of 26 to 42 cm depending on species, and average height of 17 m. Total density of the stand was 1,505 trees/ha and 29 m^2/ha basal area.

More than 90 percent of the oak forests are obtained from natural regeneration. The usual technique is a multicut shelterwood sequence: a preparation cut, seed cut, 1 or more release cuts, and final removal cut (Figure 2). The preparation cut removes all of the tolerant understory that was shading the oak stems to prevent epicormic branches. The seed cut removes 50 percent of the overstory stems and about 35 to 40 percent of the volume. The preparation and seed cuts often are done in the same year. The first release cutting, usually about 3 years after the seed cut depending on seed crops (it usually is done 2 years after a seed crop), removes another 25 percent of the stems. The final cut, 3 to 4 years after the release cutting so long as there are sufficient seedlings, removes the remaining 25 percent. Epicormic branches that form during the shelterwood sequence are not a concern as they affect only the outer 1 cm of wood and do not degrade quality or price. When seed crops do not occur or more seedlings are needed, additional time occurs between cuts and additional release cuts can be made. In some instances, 20 years can pass between the seed cut and final removal cut. Within a stand, the seed cut and subsequent cuts are spread out over 10 years so that about 1.5 to 2 ha per year is cut. This procedure evens out the flow of wood and allows more precise tracking of regeneration. The resulting stand will have an initial potential variation of 10 years in age, though variation is usually less because the bulk of the regeneration is from the same seed crops.

Planting or seeding, is done where coppice stands are being converted to high forests, where cleared land is being forested, and where poor seed crops due to late frosts or insect defoliation fail to produce natural regeneration. In many areas, seed production stands are designated. These are high-quality genetic stands used for seed collection. Tarps are spread under the trees to catch

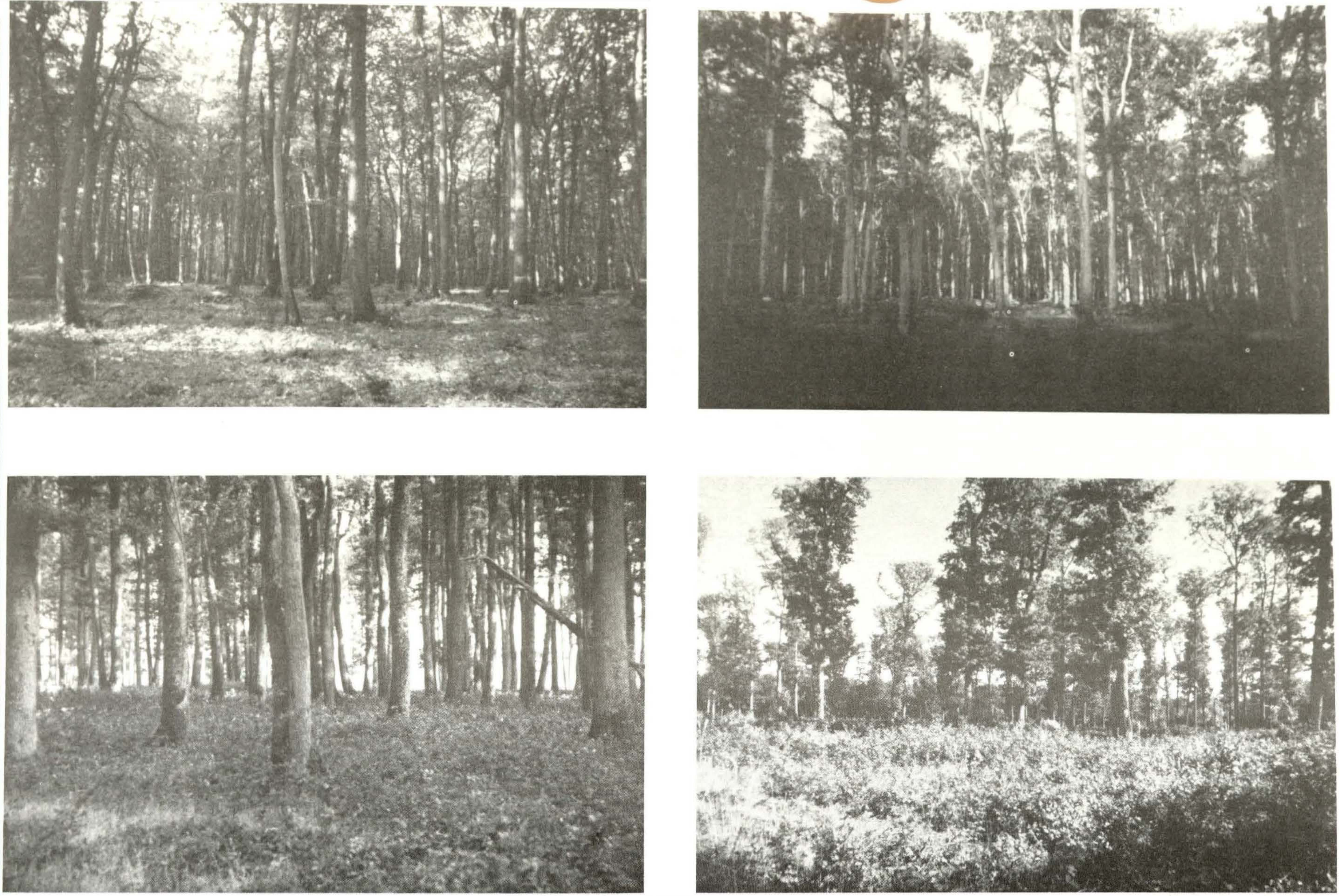


Figure 2.—Typical shelterwood sequence in a sessile oak stand. Figures 2A, B, and C are a 210-year-old stand in Blois State Forest, Figure 2D is a 180- to 200-year-old stand in Soudrain State Forest. A. Stand after the preparation cut has removed the tolerant understory, 245 trees/ha and 537 m³/ha (upper left). B. Stand after the seed cut, 158 trees/ha and 306 m³/ha (upper right). C. Stand after the first removal cut (lower left). D. Young stand of regeneration immediately after the final removal cut (in foreground), after first removal cut is in background (lower right).

acorns. Seed is used for plantations in a 100- to 150-km circular area around the stand. In France, northern red oak (*Q. rubra* L.) also is planted on some drier sites where native white oaks do not grow as well.

Weeding is an integral part of the regeneration process. It is used under the shelterwood sequence to reduce competition from grasses, weeds, shrubs, and undesirable tree species. Weeding also ensures the establishment and early growth of seedlings. Weeding is common on all forests, but what is removed and how this is accomplished varies from forest to forest. For example, in Blois State Forest, glyphosate is applied before the first cut and then manual methods are used to cut all grass that is taller than the oak seedlings. Between 5 and 7 years, the *Rubus* and all woody stems other than oak are cut. In Soudrain State Forest, fluazifop-p-butyl is applied in June to kill grass (it does not harm oak seedlings) and glyphosate is used to kill *Rubus*. Some manual weeding is done as well. Weeding costs are high by our standards. Standard regeneration costs for the Loire Region for 1983 were:

Natural regeneration

Item	*FF/ha*	*Dollars/acre*
Site preparation (ditching, herbicide, understory removal)	3,558	240
Supplementary planting (200/acre)	2,165	146
Competition control/release (manual)	16,000	1,146
Total	22,713	1,532

Artificial regeneration

Item	*FF/ha*	*Dollars/acre*
Site preparation (ditching, herbicide, mowing, pulverization)	6,078	410
Seedlings (1000/acre)	6,746	455
Planting (400/person/day)	2,595	175
Replanting (10 percent)	1,186	80
Competition control and pruning (chemical, manual, mechanical)	7,784	525
Total	24,389	1,645

Weeding is facilitated by the establishment of a system of tending trails in the stand. Major access routes, 3 to 4 m wide, are put in at intervals of 100 by 50 m and serve to mark off 0.5-ha blocks. Tending trails, 1 to 2 m wide, are then put in at right angles to the major trails; intervals are 10 to 12 m and depend on the estimated number of crop trees in the final stand. The trails usually are established by brush mowers. Weeding and subsequent cleaning operations are done intensively on both sides of the trail to a depth of 2 to 3 m and less intensively beyond that distance. Trails are recut every 4 to 5 years until they remain open.

After the stands are established and the final removal cut made, cleanings are done when the trees reach a total height of 3 to 4 m (about age 15). Cleanings remove non-oak competitors, wolf trees, and forked and crooked dominant and codominant trees. They should favor the growth and crown development of well-formed dominant trees. Species that eventually will form the understory (hornbeam, beech, linden) are not eliminated but are cut back to a smaller size than the oaks. Cleanings are continued at 6-year intervals until about age 30 (total height of 10 to 15 m). Some of the material cut in cleanings may be used for firewood. The regeneration goal is to have many thousands of oaks per hectare so that the competition will select the best trees and the dense stocking will maintain good form. During the weeding, cleaning, and thinning stages, the number of oaks is reduced tremendously.

Thinnings are begun around age 30. Before thinning, crop trees to leave are chosen — about 70 to 100/ha or one tree every 10 to 12 m. Crop trees are marked and thinnings are made to release them. A yield table (density rules) for each age is used to give the number of trees per hectare to leave in the thinning (Oswald 1981). Wood from thinnings is used for wood parquet flooring starting at age 30 and also for firewood and pulpwood. Understory species and beech are retained to provide shade on the oak stems and prevent epicormic branches. Thinnings are done every 5 to 15 years depending on site and age. Younger stands and better sites have more frequent thinnings. As stands age, sawtimber can be sold from the thinnings. Because the goal is to produce high-quality veneer, the trees must not have epicormic branches, irregular growth patterns (alternating groups of wide and narrow rings), or growth rings exceeding 2 to 2.5 mm. Therefore, light thinnings are conducted frequently to maintain uniform, narrow growth rings. Once crop trees are selected, a crown thinning is done in the first third of the rotation, followed by intermediate thinning in the middle third, and low thinning in the last third. In some areas, true crop trees are not selected until they have a clear stem of 10 to 14 m (total height of 20 m and 65 years of age). Selections before that are potential crop trees. Crop trees are selected almost exclusively from dominant trees, due to the difficulty in promoting smaller trees.

The final harvest goal is to have 70 to 100 veneer trees/ha for sessile oak (28 to 40 trees/acre) and 50 to 80 trees/ha for pedunculate oak. The trees usually will average 70 cm dbh and 2 to 2.5 mm/yr ring width and clear stems 10 to 14 m long (Figure 3). At this point, the stand is then regenerated. Trees are sold on the stump by auctions; they are marked at dbh and on the stump to provide control over the harvest. Buyers examine the trees at one time. Borings are made into the tree on all four sides below the stump line to check the color of the wood. Color determines the price that the tree will bring, with bright yellow having the most value. Branches are cut off before

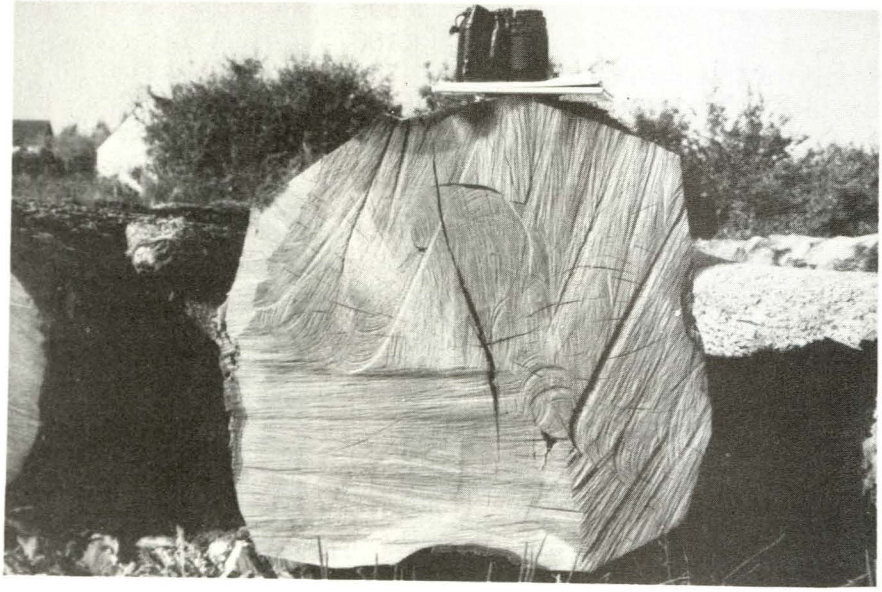


Figure 3.—Veneer log from 180 to 200-year-old tree removed in shelterwood sequence on the Soudrain State Forest in France. Diameter is about 75 cm (30 inches).

felling to prevent the veneer log from splitting. A stand in Soudrain State Forest that is being harvested in a shelterwood sequence is bringing 1 million fr/ha or $65,200/acre. The price received for the wood is 10,000-12,000 fr/m^3 ($9,120-$10,944/M bf) for the first 6 m if the color is good.

GERMANY

The Federal Republic of Germany has 7.11 million ha of forest (about half of France's area) that covers 29 percent of the total land area. This forest area accounts for slightly more than 20 percent of the EEC's forests (Anonymous 1982). The federal government owns little forest land. Most public forests are owned by state governments or communities and several other public owners. Private owners also hold significant areas of forest. In Germany, states run the forests and have State Forest Services. State foresters manage all publicly owned forests as well as all privately owned forests that are too small to employ foresters. Large private owners can employ foresters and manage their own lands but all forest land must be managed by a forester by law. If the private owner does not employ a forester, the state will manage the land and charge the landowner.

The two German states that I visited were Bavaria and Baden-Württemberg. Bavaria has 2.45 million ha of forest which is 35 percent of its land area. The forest land ownership is 53.3 percent private, 32.2 percent state, 13.1 percent community, and 1.4 percent federal. Baden-Württemberg's 1.353 million ha of forest represents 38 percent of its land area. Of this land, 41 percent is in community and other public forests, 24 percent is in state forests, and 35 percent is in private forests. Both of these states extend from low-elevation river valleys through foothills and plateaus to the Alps and Black Forest mountains. There are a variety of forests: mixed hardwoods, oak, beech, pines, Norway spruce, silver fir and larch.

Upper Franken Region of Bavaria

Würzburg is the Unterfranken (Upper Franken) Regional Office of the Bavarian State Forest Service. Unterfranken, one of seven regional offices in Bavaria, has 340,000 ha of forest divided into five forest districts and 30 forest offices (forstamt). The land ownership is 31 percent state, 40 percent community, 27 percent private, and 2 percent federal. The forest composition is 51 percent hardwoods and 49 percent conifers. Of the hardwoods, 23 percent is beech, 20 percent is oak (primarily *Q. petraea*), and 8 percent is other hardwoods (hornbeam, birch, hawthorn, mountainash, etc.). The forest in some of the area has been under management for centuries. The area lies along the Main River with plateaus and foothills of the Alps. Two main areas, Spessart and the Frankish Plateau, were included in the trip with two forstamts in each.

The Spessart or "red sandstone" region, known as the best oak growing area of Germany, is bounded by the Main River which loops around and makes the area almost square (with river on three sides). It can be divided into the Spessart foothills, North Spessart, and High Spessart Range. I visited the High Spessart Range; forests in the other two areas are predominantly coniferous. The High Spessart Range is predominantly beech forest with European oak (*Q. petraea*), hornbeam, and birch (*Betula pendula*) with a ground cover of grass, predominantly wood rush (*Luzula albida*).

The area has kept its original pure hardwood forest character because it was used as a feudal hunting preserve by the Archbishop of Mainz and the King of Bavaria. The elevation is 300 to 450 m with a maritime-influenced climate. Upper areas are cool, rainy, and foggy. The mean annual temperature is 7 to 8°C and the mean annual precipitation is 1000 to 1100 mm. There is danger of late spring frosts until the middle of May or even June and a spring drought that can damage young growth is possible due to low precipitation. The geology is Lower Red Sandstone and in the west coarse-grained Middle Red Sandstone. Clay lenses are scattered. Gentle, sloped ridges are typical while down the valley, slopes are steeper with flat areas located between them. The sandy soils that result are poor nutritionally. Clay lenses, alluvial sediments, and loamy soil can provide a better nutrient supply when mixed in. Relief and exposure is important. Site is submesic with deep sands and east to southwest exposure. There is no site mapping for this area, but there are site-class ratings (site class I = 7.5 m^3/ha/yr; site class IV = 3.5 m^3/ha/yr).

The 6,100 ha Rothenbuch forstamt was established in 1485 by the Archbishop of Mainz as a hunting preserve for mast production for wild boar and deer. From 1700 to 1850, most of Middle Europe's forests were damaged (cut, burned, and used for glassmaking) and later planted to spruce, pine, and larch. Many of these areas are now being converted to beech, oak, and maple. The first inventory was in the 18th century when every stem was counted. Seedlings (regeneration) were planted for the first time in 1790. The Rothenbuch forstamt became part of Bavaria in 1814 and part of the Bavarian State Forest Service in 1885.

The office employs six foresters, each of whom manages 1,000 ha (2,420 acres). Rothenbuch (red beech) has 36 percent conifers with a planning goal of 30 percent, and 64 percent hardwoods with a planning goal of 70 percent. The breakdown is 38 percent beech with a goal of 37 percent and 26 percent oak with a goal of 33 percent. The annual cut is 5.3 m^3/ha/yr. The volume cut is divided into 62 percent from thinnings and 38 percent from final cuts. Of the latter figure, only 7 percent is in oak veneer.

The 5,544-ha Rohrbrunn forstamt just south of Rothenbuch has many of the same characteristics. Entirely state owned, the area is 93 percent forested. The forstamt is 74 percent hardwoods (28 percent oak and 46 percent beech) and 26 percent conifers. It is divided into six areas with a forester for each. Half of all the oak veneer in Upper Franken comes from this forstamt.

The Fränkische Platte (Frankish Plateau) within the Würzburg Regional Office has a different geology. It is composed of primarily loam, chalk, and alluvium bases. The flattened area is in the rain shadow of Spessart and Rhön and has a warm, dry subcontinental climate with a long growing season. It is in a protected position and includes many wine-growing areas. The elevation ranges from 160 to 420 m in southern portion of the plateau. The average annual temperature is 6.5 to 9.0°C (14.0 to 17.0°C in May to September). The average annual precipitation is 560 to 730 mm (280 to 390 mm in May to September). The average drought index is 25 to 35. The vegetation in the southern portion is primarily oak mixed forest with some beech. A climate quotient was developed that uses the mean temperature in the warmest months divided by the yearly precipitation times 1,000. The quotient is then related to the forest vegetation type. Spessart has an index of 15 to 20 which is defined as beech-oak area. An index of 21 to 30 indicates the oak-beech-hornbeam area. Areas with values of 21 to 25 have more vigorous beech while an index of 26 to 30 indicates less beech. Areas with values above 30 are the oak-hornbeam-linden type. This climate creates many problems related to insect defoliation. Two forstamts were visited in this area.

The Würzburg forstamt has 16,621 ha of forest, of which 28 percent is state owned, 49 percent is community owned, and 23 percent is privately held. Of the area, 15 percent is forested. It has nine employees in the bureau office and nine district foresters. The average district is 1,000 ha but some are as large as 2,500 ha. There are 31 woodcutters and four apprentices. The area is characterized by an elevation of 225 to 372 m, average annual temperature of 8°C, annual precipitation of 640 mm, and late frosts. On state forests, composition is 81 percent hardwoods (48 percent beech, 21 percent oak, 12 percent mixed hardwoods) and 19 percent conifers. On private land, composition is 78 percent hardwoods (40 percent oak and 38 percent beech and mixed hardwoods) and 22 percent conifers. Harvest on state forests is 10,750 m^3 in thinnings and 12,500 m^3 in final cuts (23,250 m^3 or 5.3 m^3/ha/yr). The forstamt had profits in 1986 of 232 DM/ha or 1 million DM ($51.55/acre or $549,000). Costs for the forstamt (in percent) are:

35 for supervising of community forest, 1.46 million DM/yr
30 for final cutting and thinning
11 for regeneration
15 for cleanings and precommercial thinnings
5 for protection, 193,000 DM/yr (81,000 DM for insects and 112,000 DM for deer and boar fences).

These costs are subtracted from the income for the year to determine profits. There is no interest or carrying of costs over the rotation.

The Wiesentheid forstamt just east of Würzburg forstamt has 14,700 ha of forest or 21.3 percent of the land area. The elevation is 200 to 240 m with an average temperature of 8.5°C and a maximum annual precipitation of 500 mm (246 to 267 mm in some areas). The vegetation composition is 26 percent hardwoods (21 percent oak and 5 percent others) and 74 percent conifers primarily Scotch pine. The area is very warm and dry. Harvest is 2,000 m^3 from thinnings and 1,500 m^3 from final cuts (3,500 m^3 or 4.1 m^3/ha/yr).

Rhine Valley/Black Forest Foothills of Baden-Württemberg

Baden-Württemberg's forests are 65 percent conifers, mainly Norway spruce, Scotch pine, and silver fir, and 35 percent hardwoods. The hardwoods are made up of 20 percent beech, 7 percent oak, and 8 percent others. *Q. robur* grows in the valleys where it is humid and sites are less well drained, and *Q. petraea* grows in the foothills. Recreation is an important use of the forest; 62 percent of the state's 6 million people visit the forest at least once a week to participate in leisure walking, hiking, horseback riding, biking, or skiing. The annual hunting harvest is 130,000 roe deer, 2,100 red deer, 2,800 wild boar, 88,000 hares, and 28,000 foxes. Deer populations are excessive and damage the forest. In 1980, state forests provided 230 million DM from timber sales and 220 million DM in nontimber benefits. There are four regional offices in the state; my visit included only the Freiburg Regional Office area and two forstamts within it.

The Offenburg forstamt is north of Freiburg in the Rhine Valley. This area has special sites for German oak—very wet in spring and very dry in summer. Soils are fragile and require lots of roads to harvest. *Q. rubra* is planted on sites that do not receive enough water. In 1984, this area was affected by the gypsy moth for the first time, though there are records of periodic damage by the oak leafroller and winter moth. In areas close to the Rhine River that have high water tables, there are stands of pedunculate oak mixed with ash, sycamore maple, elm (*Ulmus glabra*), alder (*Alnus glutinosa*), cherry, and pear (*Pyrus communis*). Areas with lower water tables have some sessile oak mixed with pedunculate oak.

Markgräflerland is the region of the Rhine Valley and face of the Black Forest that extends from Freiburg in the north to Basel, Switzerland, in the south. It encompasses vineyards and oak forests in the Valley, mixed oak and beech forest in the foothills and lower elevations, and spruce-fir forests in the higher elevations of the Black Forest. It is a popular recreation area with activities such as hiking and skiing. The Müllheim forstamt is in the middle of this area, halfway between Freiburg and Basel. The oak forest area has elevations of 270 to 470 m. The average annual temperature is 9.5°C and annual precipitation is 900 mm. Soils are calcareous with a layer of loess—very fertile soils used for wine growing and hardwood forests. The natural vegetation in the foothills is beech, a strong competitor of oak. In 1873, the hardwood forest was 90 percent oak and 10 percent beech. In 1985, it was 52 percent oak, 33 percent beech, 8 percent other hardwoods, and 7 percent conifers.

There are 868 ha of oak forests with 470 ha in Müllheim. Müllheim forstamt is 6,300 ha, 1,000 ha of which is hardwood foothills. Ownership is 1,000 ha state, 5,000 ha community, and 300 ha private. The forest office has a director, one assistant, and one administrator, three secretaries, and seven forest districts. The elevation ranges from 1,220 m in the Black Forest portion of the forstamt to 400 m in the foothills and 210 m in the Rhine Valley. Precipitation ranges from 1,900 mm in the Black Forest to 1,000 mm in the foothills and 730 mm in the Rhine Valley. Precipitation during the growing season is 600, 430, and 330 mm, respectively. The average annual temperature is 4.5, 9.2, and 10°C, respectively, while the growing season temperature is 12, 16.3, and 17°C.

The Black Forest has soils from granite and kneiss bedrock. Native vegetation is silver fir (*Abies alba*) and beech while Norway spruce and Douglas-fir have been introduced (about 25 percent each). The composition of the forstamt is 57 percent conifers and 43 percent hardwoods (18 percent beech, 10 percent oak, 2 percent hornbeam, and 13 percent other). The annual harvest is 6.6 m^3/ha/yr.

Oak Silviculture and Management

In contrast to France, Germany has not prepared an ecological site classification for the country. The amount of site work varies widely from state to state and region to region within a state. Most areas have maps of their forests that incorporate some type of productivity measure and perhaps information on soils. Other areas have more detailed maps that provide information on soils, moisture status, climate, vegetation, and the probability of storms, drought, and insect attack. A higher proportion of the German information is based on long-term experience with the sites.

The management goal for Germany's oak forests is similar to that for oak forests in France—the production of high-value products, particularly veneer, on long rotations. Long rotations also satisfy many of the social amenities connected with forests and results in the production of firewood, pulpwood, and sawtimber as intermediate yields. One social need not satisfied is that for natural forest areas. Beginning early in this century, Bavaria began to set aside certain forest areas as natural areas that will not be managed. In addition, the federal government has set aside a few parks that will not be managed. While all of the states and regions in Germany have the same management goal, the approach can vary. For instance, the philosophy of oak culture in the Würzburg area is to produce wood with narrow annual growth rings and a tall clear bole. This goal encompasses three stages: in the first stage, about 100 to 150 years, a clear stem is grown to a height of 20 to 25 m, the second stage, about 200 to 300 years, is marked by frequent thinning to allow continual growth at a uniform rate; in the third stage, from 300 to 600 years, all mature trees are harvested slowly over time and then the stand is regenerated (Fleder 1981).

In Freiburg, the goal is to grow shorter, fatter trees in less time, (faster growth and wider rings). The first 40 years are spent in stem reduction as good-quality, spaced trees are encouraged; the second stage, from 40 to 140 years, is spent selecting crop trees and thinning to produce knot-free wood on the crop trees; the last period, from 140 years to rotation age, is spent caring for crop trees and harvesting declining trees, and then harvesting at rotation (Kenk 1984).

Regeneration in Germany is a combination of natural and artificial processes. All of the higher productivity oak sites have beech as the climax forest type, so they have to work against succession. Most regeneration is done through a shelterwood sequence, but clearcutting is sometimes used. A two- or three-cut sequence consists of a preparation/seed cut and final removal cut or a preparation/seed cut, first removal cut, and final removal cut. All regeneration work is timed to acorn crops. In Spessart, seed crops are obtained every 7 to 10 years, so sufficient area must regenerated in one year for the next 7 to 10 years of forest regulation. In Würzburg and Wiesentheid, seed crops occur every 6 years. In Müllheim, seed crops are infrequent due to late frosts and insect defoliators.

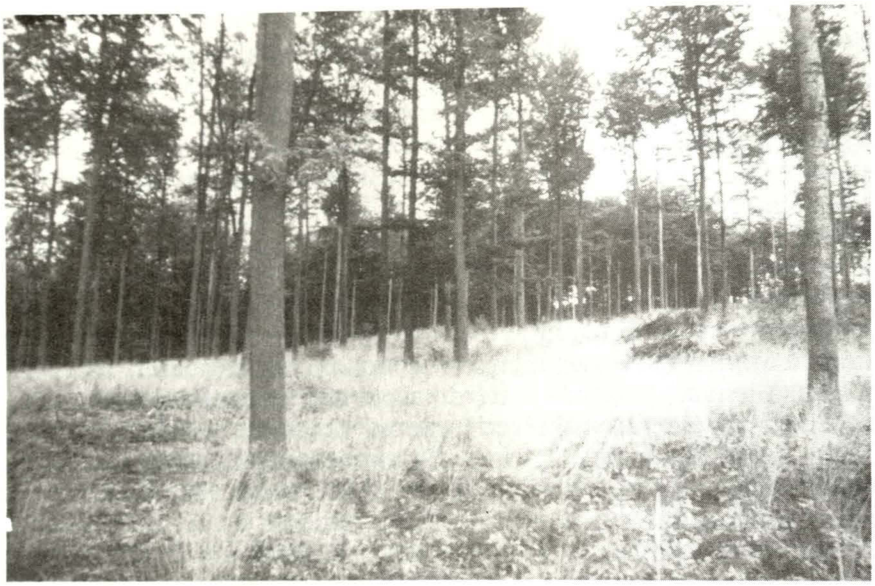
In Spessart, all regeneration is geared toward mast crops. In spring, the flower crop is inspected for damage by insects or late frosts. In summer, the crop is checked again and in mid-September the acorns are ripe. In October, a shelterwood cut removes 50 percent of the stand (Fig. 4). Branches are then removed and given to citizens for firewood. Licenses are issued for the collection of acorns. By law, acorns can be collected only from recommended stands. Sellers receive 100 DM for 50 kg of acorns ($0.50/lb). In 1982, the last mast year, 6000 kg of acorns were collected.

After the shelterwood cut has been completed, a fence is installed to keep out wild boar and roe deer. The site is prepared with a machine that makes rows for seeding (the wheel frees mineral soil), 800 kg/ha of acorns are sown by a crew of 10 to 20 people (usually women), and the acorns are covered with soil (5 cm or deeper is better to avoid late spring frosts) (Nüßlein 1978). The shelterwood is used to provide natural regeneration of beech along with the oak, protect seedlings from frost and heat, and reduce grass growth. This process, which imitates natural regeneration of oak, produces 100,000 natural oak seedlings to 10,000 beech seedlings/ha. Beech usually is left in the overwood as all of the oak veneer has been removed by the time the stand is regenerated. The area is seeded from October until late December. In 1983, nearly 80 ha were regenerated from the 1982 seed crop. Oak seedlings are transplanted from dense areas to areas that need seedlings. Light grass is not a problem, but heavy grass is packed down by snow and mice girdle the seedlings under the grass. Beech is used to give high shade to oak trunks and keep them free of branches. Beech seedlings and oak seedlings with low branches are cut at 5 to 6 years. Oak seedlings with clear stems are left to grow with the new stand. When seedlings are 1 to 1.5 m tall, removal of the overwood is begun. The fence is left for 10 to 15 years. Manual weeding is done to remove heavy grass, birch, and conifers and to prune the beech below the oaks. *Rubus* is not a serious problem. In 1982, the cost of regenerating the stand (Figure 5) was:

Item	**DM/ha**	**Dollars/acre**
Removing brushwood/slash	1,500	333
Preparing seedbed	500	111
Acorns	800	178
Hand sowing	2,000	444
Fencing (8-foot woven wire)	1,200	267
Total	6,000	1,333

The cost range is 6,000 to 9,000 DM/ha or $1,333 to 2,000/acre. Costs for weed control are 1,500 DM/ha ($333/acre) per year for 3 years and 200 DM/ha ($44/acre) per year for mouse control.

In the Freiburg region, seed production is irregular due to late frosts and insect defoliation. Oak is managed partially with natural regeneration and partially by planting. Fifteen years ago, 10,000 to 12,000 seedlings/ha were planted; this amount has since been reduced to 3,000 to 3,500/ha, including 1,500 hornbeam seedlings/ha. Beech sometimes is planted as well, 1,000 to 2,000 oaks/ha are planted and natural seedlings of beech, birch, hornbeam, etc. are used to fill in. Early tending measures are used to keep the oaks dominant. Site/species selection criteria are again being used to prevent offsite problems that have developed on past plantings. In the future, oak will account for 10 to 15 percent of the forest (70 to 80 percent of it managed by planting and 20 to 30 percent by natural regeneration). In some areas, coppice with standards may be used to reduce the costs of establishing oak stands. In the flat Rhine Valley forests of Baden-Württemberg, 20 to 25 percent of the area is planted to *Q. rubra* because of its better growth on the drier sites (average yield of 8 to 10 m^3/ha/yr). The cost of establishing 1 ha by planting to end of the cultivation phase including fencing, weeding, cleaning, etc. ranges from 10,000 to 12,000 DM to 25,000 DM ($2,222/acre to $5,555/acre). The cost of natural regeneration ranges from 8,000 DM to 12,000 to 14,000 DM/ha ($1,778/acre to $3,111/acre).



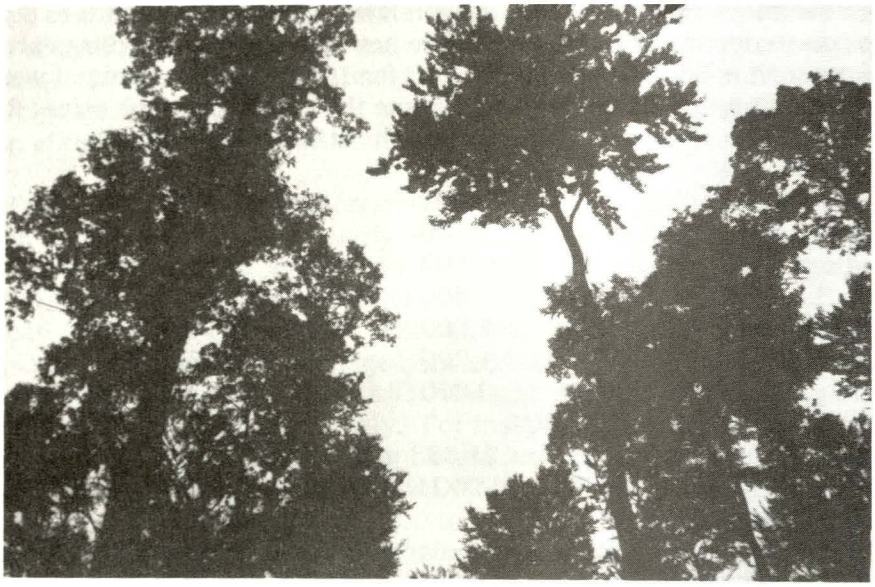


Figure 4.—A shelterwood cut in Spessart area of Germany, Rothenbuch forstamt, completed in 1982, provided shelter for direct seeded seedlings. A. Overstory has been reduced by 50 percent and grass cover results (upper). B. Crown coverage from 50-percent reduction (lower).

In planting, the soil is not prepared due to compaction problems. Planting stock usually is 60 to 70 cm tall. Fencing is used to protect seedlings from roe deer and wild boar. Due to severe weed competition from *Rubus*, the stands are weeded twice in the first year and then once a year until the 5th or 6th year. The seedlings are fertilized 1 year after planting with a handful per tree. Because of early fall or late spring snows can bend the seedlings, a wide spacing is used to give each stem more stability. Major disadvantages of planting are high costs and difficulty in obtaining sufficient quality seed.

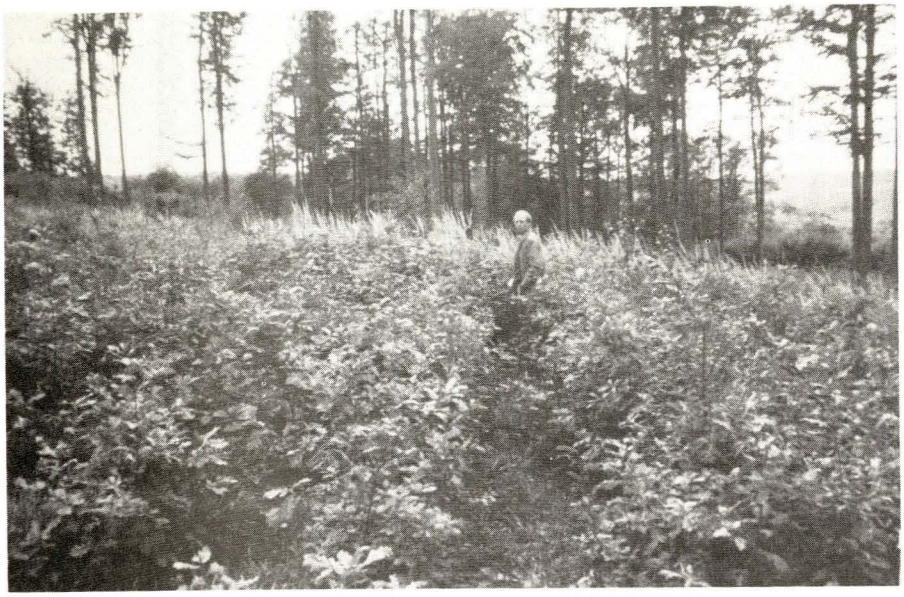


Figure 5.—Direct seeded 6-year-old seedlings from 1982 seed crop in Spessart Region. The seedlings are under the shelterwood in Figure 4 and have been weeded manually.

Natural regeneration of oak from seed can occur when there are good seed crops as in 1984 in the Freiburg region. A preparation cut removed one-third of the growing stock following natural regeneration from the seed crop. A first removal cut removed another one-third after 2 years, and a final removal cut the remaining one-third after 5 years (another 3 years). The area has 70,000 to 300,000 seedlings/ha. Atrazine and indolebutyric acid for 1 year controlled grass, but had limited success against *Rubus*. *Rubus* was manually cut to give oak enough light to keep them above the weeds. In 1988, rows were marked in the natural seedlings. Oak seedlings in between rows were removed by mowing or cutting. Some of these seedlings were transplanted into areas of rows without seedlings. Manual weeding was done twice. The high density of seedlings should be lowered as fast as possible. This will be accomplished by transplanting seedlings to other clearcuts and doing precommercial thinnings and cleanings. Natural regeneration can be obtained in 1 year if a clearcut is made immediately after the seedlings appear.

As in France, early cleanings in Germany are used to set up paths in the stand. In natural regeneration, a common arrangement is a 1-m-wide path at spacings of about 30 m. The purpose of the cleanings is to remove conifers, birch, and oak wolf trees. Beech are cut off below the oaks but not eliminated. Where beech is weak, some oaks may be cut to improve it. Oaks are kept dense to prevent forking and are thinned by natural competition (Figure 6). In planted stands, cleanings remove non-oaks within and between rows. A stand is cleaned from about age 4 to 20. The switch to thinnings occurs at about 20 years of age, earlier than in France.

In Germany, the first 2 to 3 thinnings (ages 20 to 50, up to 80) are precommercial, with most of the wood used for firewood. In Müllheim, farmers come do the cutting in exchange for the wood at no cost or for a small fee. In Spessart, this wood may be used by the forstamt or sold. In all areas, the small trees cut in these early thinnings are cut into 1-m-long pieces and carried from the woods to prevent damage to residual trees. These thinnings are done by selecting crop trees and carefully promoting them through crown thinnings to increase crown size; wolf trees not removed in cleanings also are removed. Beech is retained in the understory to shade the oak stems and prevent epicormic branches. Thinnings at intervals of 10 to 15 years maintain a uniform growth

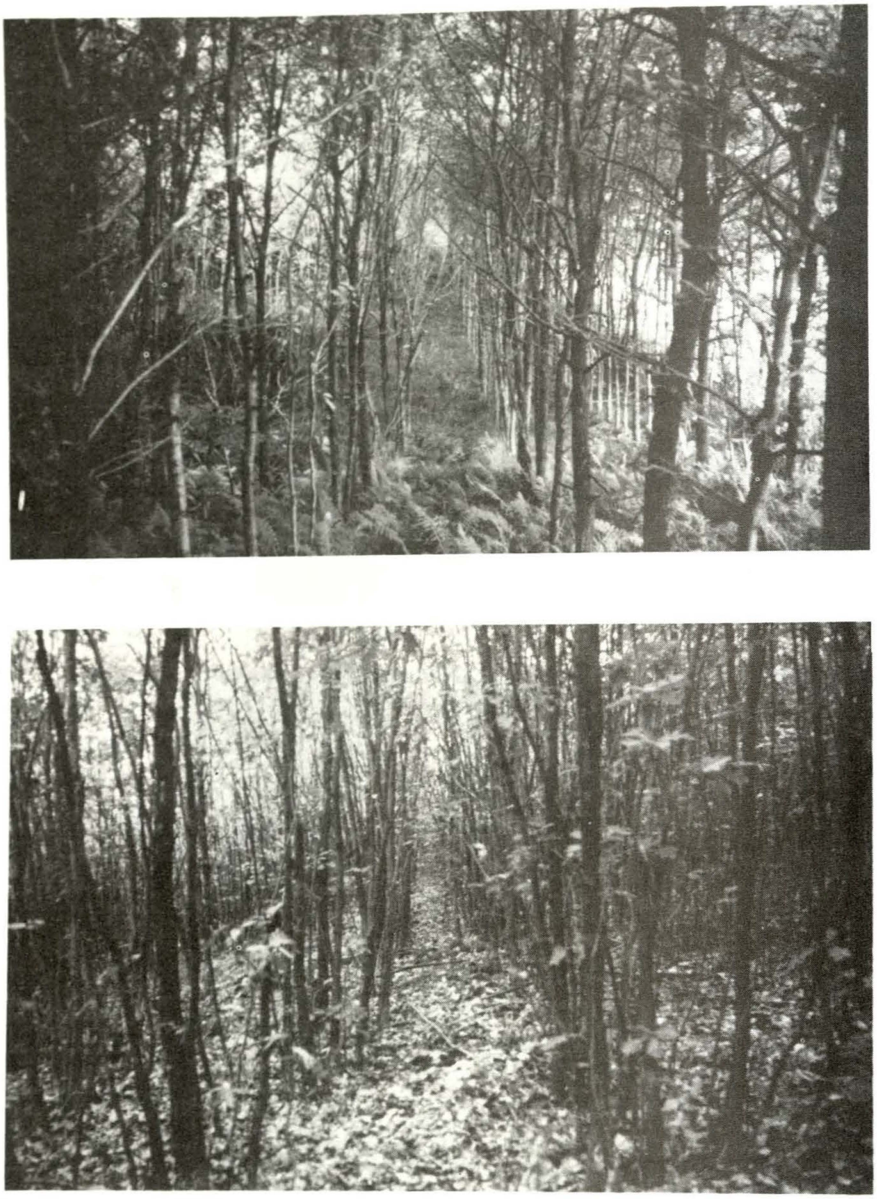


Figure 6.—Young managed stands in Germany. A. Stand in Müllheim forstamt is 10 to 15 years old after planting in 1-m spacing by 2.1-m rows. Cleanings have removed other competitors. Precommercial thinning has not began because the stand is still naturally pruning (upper). B. 18-year-old stand in Rothenbuch forstamt that was direct seeded in 1970. It was cleaned in 1974 and again in 1986-87. Access paths were cut in 1981 (lower).

rate. Most areas select 80 to 100 crop trees/ha by age 30 to 40 (Figure 7). In some areas, precommercial thinnings do not begin until natural pruning is completed.

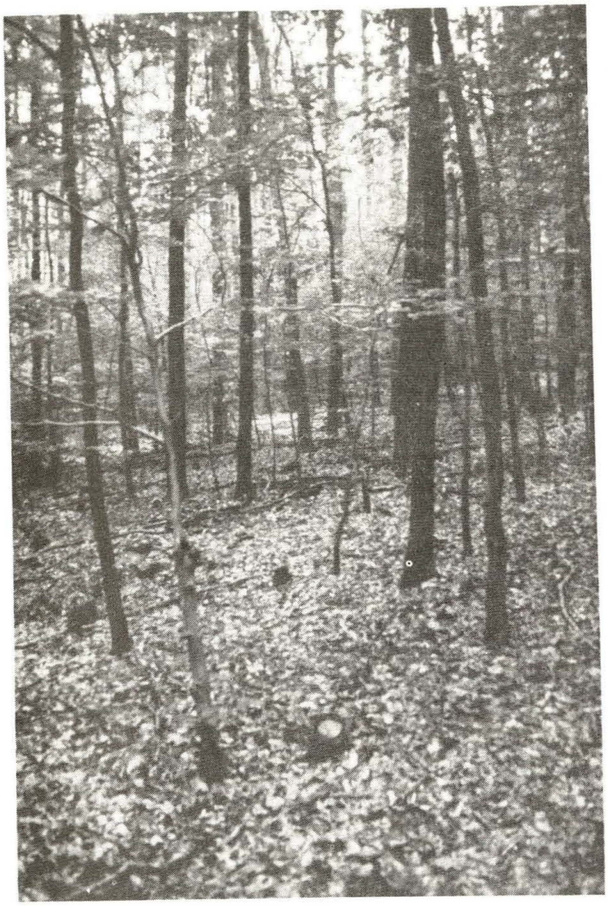


Figure 7.—50-year-old crop tree that has just been released in Müllheim forstamt (note stumps). Beech understory trees were not cut.

Commercial thinning begins at 50 to 80 years depending on the region. Small-diameter trees are sold for parquet flooring and large trees for sawtimber. All trees that are competing with the crop trees are removed. In Spessart, all marking is done by crowns; a tree must have a good crown to be left. Thinning goals are to continue increasing crown size on crop trees and maintaining uniform growth (Spiecker 1983). In the State of Baden-Württemberg, thinning for crown size ends at age 120 to 140. This is followed by thinning based on caring for the growing stock, a low thinning approach by which declining and rotten trees of oak and beech are removed while beech is maintained in the understory. Beech trees are removed as soon as they begin to grow into the oak crowns. They are quickly replaced by smaller beech trees, and shade on the oak stems is maintained. Natural regeneration of the beech under these conditions is easily obtained. Using beech rather than understory trees like hornbeam or linden results in harvests of high-quality beech sawtimber (and veneer) rather than firewood.

The Spessart region uses a similar commercial thinning system, but thinning is continued until around age 200 before the switch to low thinnings. The goal at age 200 is 71 trees/ha, a height of 33.2 m, basal area of 27.4 m^2/ha, and volume of 500 m^3/ha. This goal is similar to the final harvest goal in France. In the Spessart region, the beech understory also is used to keep the oaks branch free and to produce sawtimber. Before 1840, pure oak stands with no beech were created and the problem with oak branches and short clear stems was discovered. In 1840, beech was planted in the understory of oak stands and in all new stands since then (as planted or natural regeneration) to improve stem quality. It is possible to obtain two or three rotations of beech sawtimber (140 to 150 years) from one rotation of oak.

In Baden-Württemberg, the rotation is 220 to 230 years for *Q. petraea* and 160 to 180 years for *Q. robur*. In Spessart, the rotation for sessile oak is 240 years, though many trees are carried longer. In drier areas of Upper Franken, the rotation is 150 to 160 years. The goal is to have trees that average 70 cm at rotation, similar to France's goal. Goals for clear bole differ with regions: Spessart wants 18 to 20 m while other areas are satisfied with 4 to 12 m. Spessart often holds the oak veneer trees from age 200 to 600, slowly cutting out veneer trees and allowing beech to replace them. The stands move from oak stands with beech understory to mixed oak-beech stands to beech stands (Figure 8). After all of the oak has been cut out, the beech is left for 10 to 50 years. A shelterwood cut then is done with seeding of oak beneath the beech. Minimum product diameters are 20 cm for parquet flooring, 25 cm for sawlogs, and 35 cm for veneer. It is possible to sell veneer from thinnings in some stands. In Germany, all trees are harvested by state crews. The material is then sold as decked wood. Information on the wood to be sold is published and mailed to buyers, who have three weeks to inspect it before the auction. Separate auctions are held for sawtimber and veneer, the latter is harvested only in the winter. Auctions generally are held in December and March. The average price for oak veneer is 1700 to 1800 DM/m^3 or $5,289-5,600/M bf. In 1983, the Rohrbrunn forstamt sold one veneer tree with three logs that set a record for price and income. The tree brought 72,000 DM ($39,528) broken down as:

Log	**Length**	**Middiameter**	**Volume**	**DM/m^3**	**Dollars/M bf**
1	9.1 m	77 cm	4.24 m^3	14,150	44,021
2	5.7 m	67 cm	2.01 m^3	4,910	15,275
3	3.6 m	61 cm	1.05 m^3	2,110	6,564

The third log, starting at a height of 49 feet extending to 61 feet, brought about the same price as oak veneer in the United States, while the lower logs brought up to eight times the price of our veneer. At a 1987 auction a two log tree brought 62,347.6 DM ($34,229). As in France, color is important in determining the value of the log; bright yellow has the highest value while gray or red colors bring lower prices.

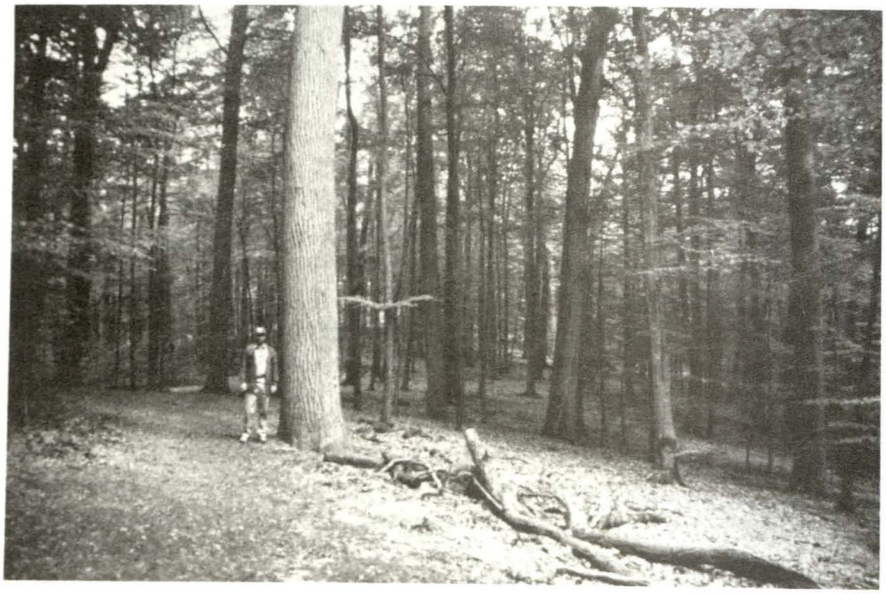


Figure 8.—360-year-old stand in Rohrbrunn Forstamt that is mature and slowly being harvested. It is now a mixed oak-beech stand with well-developed beech sawtimber. Eventually it will be regenerated after all of the oak has been harvested.

DEFOLIATION IMPACTS

In both France and Germany, two defoliating insects, the oak leafroller (*Tortrix viridana* L.) and the winter moth, (*Operopthera brumata* L.) occurred, often together, in outbreaks in all oak stands. Apparently, there were some differences in outbreak frequency in different areas and climates, but there was insufficient information to discover a pattern. Both species defoliate very early in the growing season. Major defoliation effects are loss of seed crops and growth loss; mortality is rare. The oaks recover quickly from this early defoliation without incurring severe damage. However, the effect on seed crops is severe in most areas. In the Müllheim forstamt, almost yearly outbreaks of oak leafroller and winter moth since 1958 have resulted in little or no natural reproduction in the area most years. In some areas, defoliation also is caused by less widespread insects. In the Spessart region, defoliation was caused by the large winter inchworm (*Hibernia defoliaria*); the common wanderer moth (*Thaumetopoa processionea*) caused defoliation in the Bourges region of France; and several species of Noctuids have defoliated trees in the Frankish Plateau of Germany.

Outbreaks of the gypsy moth (*Lymantria dispar* L.), the other major oak defoliator in Europe, are smaller and appear confined to specific climatic and site conditions. Apparently, gypsy moth outbreaks are restricted to warm, dry climates and sites that are warm and dry, especially during the larval period. In Germany, gypsy moth is considered a major pest only in areas with fruit (apple) orchards and vineyards. The Spessart region, which is cool and moist, has never had a gypsy moth outbreak, while the Frankish Plateau, only 10 to 30 km to the east with a warm, dry climate, has the most frequent and numerous gypsy moth outbreaks in Germany. The stands in both areas are predominantly sessile oak.

Gypsy moth has occurred in the warmer Rhine Valley on the Offenburg Forstamt, but not in the cooler, moister foothills of the Black Forest in Müllheim forstamt, only tens of kilometers away. In the warm and dry Bourges region of France, the gypsy moth often is accompanied by other defoliators. In the Frankish Plateau in Germany, the gypsy moth, oak leafroller, winter moth, and Noctuids together caused defoliation at various locations from 1979 to 1988.

As with the oak leafroller and winter moth, the major effects of gypsy moth defoliation in oak stands are loss of seed or mast crops and growth loss. However, tree mortality can occur following defoliation by gypsy moth. Such defoliation occurs in late spring and early summer and damages the lammas (long shoot) growth of the oaks. When all three insects interact, the oaks are defoliated early, refoliate, and then are defoliated again by gypsy moth. In this situation, crown dieback and eventually mortality can occur (Figure 9). Mortality also results when refoliated leaves are infected with the European powdery mildew (*Microsphaera alphitoides* (Grif. and Maubl.)), a fungal disease. In the Frankish Plateau, many defoliated trees die following an attack by the cambial borer, *Agrilus biguttus*.

Mortality increases in importance on drier sites. In the Bourges region, there was an inverse relationship between soil depth and mortality, especially with pedunculate oak. Poor silviculture also contributes to increased mortality in stands. Many areas that are heavily and frequently defoliated by gypsy moth are managed or have been managed as coppice with standards (Figure 10). A lack of thinning that creates stands that are too dense or overstocked results in trees with smaller, thinner crowns and increased mortality due to lowered tree vigor and poorer crowns. Mortality also increases in trees of advanced age. In most areas of France and Germany, tree mortality is only 5 to 10 percent in most gypsy moth areas. Most of this mortality is salvaged promptly, so one rarely observes dead trees in the stands. In the Offenburg forstamt, however, mortality in pedunculate oak was 40 to 50 percent following 2 to 3 years of defoliation combined with powdery mildew infection in the last year. In Thoux Forest in the Bourges region of France, mortality of oak standards exceeded 80 percent on half of the area and ranged from 0 to 30 percent on the other half. Mortality was greater on shallower soils and where there was more pedunculate oak than sessile oak.

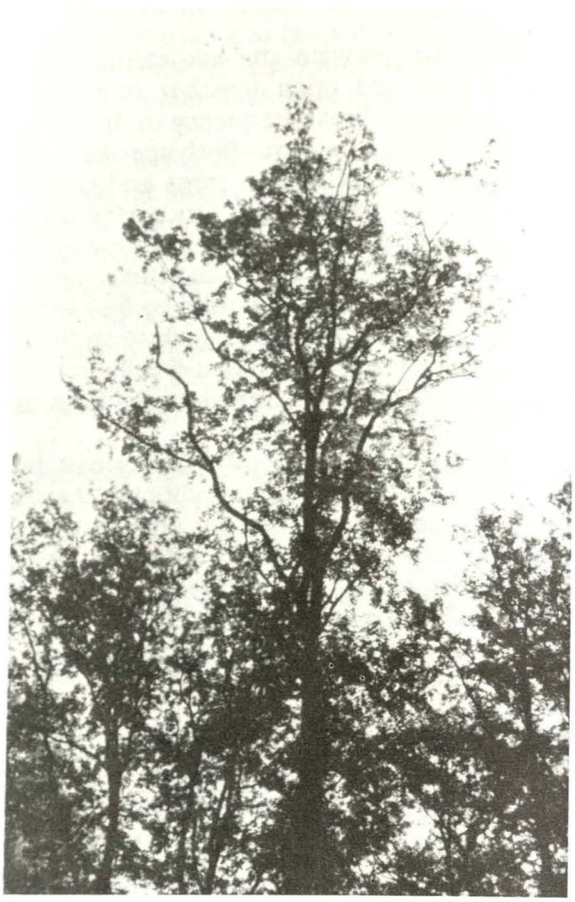


Figure 9.—Crown dieback in 200-year-old sessile oak on the Soudrain Forest in France. Gypsy moth defoliated the stand completely for two years, resulting in mortality of 6 to 8 percent.

Control of defoliating insects is done with aerial application of insecticides by helicopter. Small blocks of 60 to 70 ha are marked with hydrogen-filled balloons. The most common material used is Dimilin which is applied at 40 l/ha and 300 g/ha. The dose may soon be reduced to 159 g/ha. Ultra-low volume applications are not allowed due to the high drift that results. The bacteria, *Bacillus thuringiensis* or *Bt* is also commonly used, especially on insects other than gypsy moth. Pyrethrins are used in situations where large larvae must be sprayed. Viruses are used to a small extent when possible. Thresholds for treatment are: 1 to 2 egg masses per lower 2 m of stem for gypsy moth (equals 20 egg masses per tree); 1 female moth per cm of circumference on sticky bands around the tree for winter moth; and 500 eggs per 1000 buds (1 egg/2 buds) for oak leafroller when in combination with gypsy moth.

CONCLUSIONS

Defoliation impacts in French and German oak forests have serious implications for silviculture and management. The most severe is the loss of acorn crops. A lack of mast for wildlife, a major

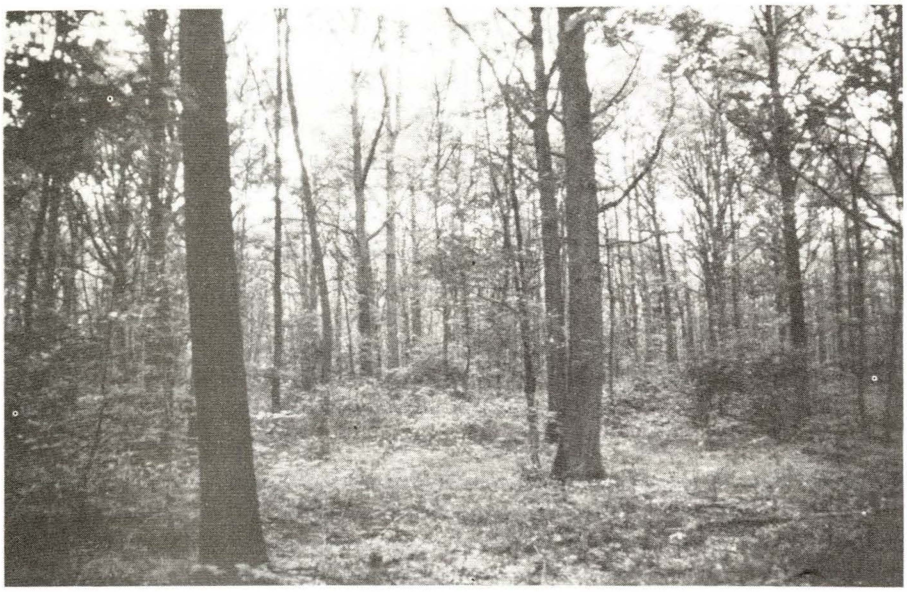


Figure 10.—Oak stands managed as coppice with standards that are frequently defoliated by gypsy moth. A 110-year-old stand that was managed as coppice with standards until 1900. Located in Poppenhecke on the Frankish Plateau of Germany, it has old oak with little understory. The area was defoliated by the gypsy moth and oak leafroller in 1980 and by the winter moth in 1986-88.

use of oak forests, and lack of seed for regeneration are other concerns. The latter concern drives the entire silvicultural system for regeneration in many areas. Planting and direct seeding are used to circumvent problems associated with a lack of natural regeneration due to poor seed crops. The loss of diameter growth and wood volume is less serious. Since most areas are managed to produce high-quality veneer with uniformly narrow growth rings, defoliation does not affect quality as it would if trees were being managed for uniformly wide growth rings.

Growth loss is affected more by gypsy moth than by other defoliating insects. Gypsy moth causes more mortality, though usually less than 10 percent. This level of mortality is not a limitation to silviculture, the dead trees being salvaged as part of the normal thinning process. In rare situations where mortality is heavy, difficult silvicultural and managerial decisions are needed. For example, in the Offenburg forstamt, where mortality in young to middle-aged stands was heavy, do you manage understocked stands with severe epicormic branches that reduce the potential for quality wood or do you prematurely regenerate them?

With regard to the silviculture and management of oak forests in France and Germany, differences are most apparent when one looks at the regeneration process. The use of natural regeneration versus direct seeding/planting depended on the frequency of seed crops, climate, and insect defoliations. Unlike France, Germany fences to exclude roe deer and wild boar. However, there also are many similarities: intensive weeding is used to establish and promote the growth of young seedlings; tending trails are used to facilitate early entry for cleanings that remove wolf trees and non-oak competitors; crop trees are selected at young ages and thinned to promote crown development first and then a uniform growth rate; and understory trees and beech are used to shade oak stems to prevent epicormic branches while producing high-quality veneer. In addition, management is toward trees that are 200 to 240 years old and an average final diameter of 70 cm, though there are differences in height of clear stem, with Spessart managing for 18 to 20 m as opposed to shorter heights. Spessart also harvests mature trees over long periods with eventual conversion to beech before initiating the regeneration process; while other areas regenerate at the end of the rotation.

Differences in the silviculture and management of oak forests in France and Germany versus the United States are nearly too numerous to mention. Our rotations generally are much shorter but final diameters are similar, so we grow trees much faster with wider growth rings. And our stands are usually managed for sawtimber, though some logs are used for veneer. Also, management in the United States generally is much less intensive: cleanings are rare and commercial thinnings are less frequent. Because our markets for small-diameter oak are much poorer, we thin initially at older ages and larger sizes. As a result, natural competition and overstocking play a larger role in the development and health of U.S. stands. These overstocked stands with small crowned trees are more vulnerable to mortality when defoliated by insects than are intensively managed stands in Europe.

During regeneration, we generally do not pay as close attention to seed crops and do not spend as much time and money on intensive weeding, fencing, and other cultural practices. One factor contributing to this difference is the accounting methods used for these expenditures. In Europe, the forests need show a profit only on an annual basis; all regeneration and other management expenses are paid for from that year's income, whether from timber sales, hunting, etc. In contrast to the United States, there is no tracking of investments at compound interest rates over the rotation.

Similarities between Europe and the United States include an attention to silvical and ecological site factors that affect productivity and management actions, and a desire to regenerate and manage oaks on high quality, productive sites. On these highly productive sites, management for oaks is fighting succession to other species. In Germany, for example, most of the productive sites would become beech stands except for the intensive management that keeps beech secondary to oak. In natural areas set aside to show what happens without intensive management, beech is growing through the oak crowns and killing the oaks. In the United States, we also are fighting a battle against succession on the best sites, but we have been unable to develop biologically and economically effective silvicultural treatments to allow oak to prevail. Perhaps we should take a lesson or two from Europe and look at more intensive management practices in some areas, especially regeneration, and at how we finance silviculture and management.

LITERATURE CITED

Anonymous. 1982. Woodlands and forestry in Baden-Württemberg. State of Baden-Württemberg, Ministry of Food, Agriculture, Environment, and Forests. Stuttgart, Federal Republic of Germany. 36 p.

Anonymous. 1984. Facts and figures on French forest resources. Ministry of Agriculture, Division of Forests, Paris, France.

Fleder, W. 1981. Furniereichenwirtschaft heute: Qualitätsansprüche, produktionszeitraum und waldbauliche folgerungen. Holz-Zentralblatt, Stuttgart 107(98): 1509-1511.

Kenk, Georg. 1984. Werteichenproduktion und ihre verbesserung in Baden-Württemberg. Allgemeine Forst Zeitschrift 17/18: 428-429.

Nüßlein, Hubert. 1978. Eichenmasten im Spessart und ihre ausnutzung. Allgemeine Forst Zeitschrift 33: 667-668.

Oswald, H. 1981. Résultats principaux des places d'expérience de chêne du Centre National de Recherches Forestières. Revue Forestière Française 33: 65-85.

Oswald, Helfried. 1982. Sylviculture of oak and beech high forests in France. p. 31-39 In: Malcolm, Douglas C., Julian Evans, and Peter N. Edwards, eds. Broadleaves in Britain, future management and research, Proceedings of a symposium, July 7-9, 1982. University of Technology, Loughborough, UK.

Spiecker, H. 1983. Durchforstungsansätze bei eiche unter besonderer berücksichtigung des dickenwachstums (Thinning intensity in oak stands with regard to diameter growth). Allgemeine Forst und Jagdzeitung 154: 21-36.

Comparative Physiology of a Central Hardwood Old-Growth Forest Canopy and Forest Gap

A.R. Gillespie, J. Waterman, and K. Saylors[1]

Abstract: Concerns of poor oak regeneration, changing climate, biodiversity patterns, and carbon cycling in the Central Hardwoods have prompted ecological and physiological studies of old-growth forests and their role in maintaining the landscape. To examine the effects of old-growth canopy structure on the physiological productivity of overstory and understory species, we measured physiological parameters of canopy trees in an old-growth oak-maple forest in east-central Indiana. Mid-day measurements of photosynthesis, transpiration, stomatal conductance, photosynthetically-active radiation, humidity, vapor pressure deficit, air temperature, and ambient carbon dioxide levels were taken during the peak of the growing season along the profile of a canopy gap within the forest, and along a height transect within the continuous canopy. Productivity, physiological, and micro-environmental profiles are presented for this old-growth forest and their relationship to current and future tree species composition and forest structure is discussed.

As we move toward the 21st century, our forests of the Central Hardwood Region are moving as well. With the establishment of many of our current forests near the beginning of this century, these mostly even-aged stands are aging, experiencing mortality, and becoming uneven-aged in structure. The growing restrictions on even-aged management will accelerate this metamorphosis. Thus, in many parts of the Central Hardwood Region, foresters must adapt to a changing management regime, recognizing changes in forest structure and composition of species. In the Central Hardwood Region, there is already experience with uneven-aged management, though favored species such as oaks (*Quercus* spp.) are discriminated against due to shade in uneven-aged cuts. And there are ecological studies of individual tree mortality and gap dynamics in these forests (e.g. Runkle, 1991; Parker et al., 1985). What can these studies and management experiences tell the land manager? What information can the silviculturist derive for vegetation management? What the practicing forester finds is a sugar maple (*Acer saccharum* Marsh.) forest replacing oak, usually one to several trees at a time on tracts receiving only partial cutting. The pattern is evident, but we may learn from the casual mechanisms.

If we examine forest dynamics in the eastern U.S., we find that forests can regenerate following major natural disturbances or through replacement of canopy trees, either singly or in small groups, from natural gap formation. The Central Region is mostly characterized by the latter type of disturbance regime and resulting canopy dynamics (Runkle, 1990). The resulting canopy structures and stand age class distributions also influence habitat for regional or migratory wildlife.

When studying the silvics of gap formation and resulting tree regeneration, old-growth forests of the Central Hardwood Region can provide important information for management. These are the forests we might expect to be relatively stable as surrounding forest changes through repeated disturbance and natural succession. These forests are important because of their role in maintaining diversity and habitat for late-successional species in the Midwest landscape. But also because gap formation, characteristic of old-growth forest dynamics, is a natural phenomenon increasingly being mimicked through silvicultural operations in this region. Unfortunately, many of these forests are also undergoing change (e.g. Parker et al. 1985; Botkin, 1990). The pattern again is evident, old-growth oak (usually mesic-site oaks) being replaced by sugar maple. The operative physiological and ecological mechanisms, and their implications for uneven-aged silviculture, are the subject of this research.

---

[1] Dept. of Forestry and Natural Resources, Purdue University, 1159 Forestry Building, West Lafayette, IN 47907-1159.

METHODS

A study has been initiated to examine in detail the physiological processes of different canopy layers in an old-growth forest in east-central Indiana and how they scale up to the ecological processes of succession through gap dynamics. This report is of a preliminary comparison of environmental and physiological parameters between intact old-growth canopy structure and a gap within the canopy.

Study Location and Stand Description

The present study is being conducted in a 20.6 ha old-growth forest remnant on the Davis-Purdue Agricultural Center in Randolph County, IN (Section 23, T21N, R12E). This wet-site oak forest, managed as a research natural area since 1917 by Purdue's Department of Forestry and Natural Resources, is located within the Tipton Till Plain physiographic province (Homoya et al., 1985). Overstory old-growth oaks consist of red oak (*Quercus rubra* L.), white oak (*Q. alba* L.), bur oak (*Q. macrocarpa* Michx.), swamp white oak (*Q. bicolor* Willd.), chinkapin oak (*Q. muehlenbergii* Engelm.), shumard oak (*Q. shumardii* Buckl.), and pin oak (*Q. palustris* Muenchh.). Long-term forest dynamics of this forest have been monitored by the tagging and monitoring of each stem ($\geq$ 10.0 cm dbh) since 1926 (Prentice, 1927; Parker et al., 1985). The last reported structural analysis of this stand (Parker et al., 1985) showed increasing numbers of tree species and increasing stem density and stand basal area (to 320 trees ha^{-1} and 31 m^2 ha^{-1}, respectively). Though basal area growth was mostly associated with residual old-growth oak stems, increasing density was a function of new individuals of sugar maple, Ohio buckeye (*Aesculus glabra* (Willd.), shagbark hickory (*Carya ovata* (Mill.) K. Koch), American elm (*Ulmus americana* L.), and American hornbeam (*Carpinus caroliniana* L.). Additionally, new stems of sugar maple and American elm also contributed significantly to increased basal area. The diameter distribution of the stand is well-represented by the negative exponential model or "inverse J-shaped" curve typical of uneven-aged stands.

Canopy Measurements

During 1991, two 30 m towers were erected into the canopy of the old-growth forest. The first was located in continuous canopy (Figure 1) where multiple stems surrounded the tower, and their crowns and others intersected the tower at multiple levels within the canopy. The second tower was located at the western edge of a roughly circular canopy gap, approximately 10-15 m in diameter. Old-growth shumard oak and shagbark hickory intersected the tower at upper levels. Sugar maple and American elm were found near the base of the tower at the edge of the gap. Previously, elms would have intersected this tower at approximately 5 and 7 m, but recent mortality due to dutch elm disease left standing snags adjacent to the tower (Figure 2).

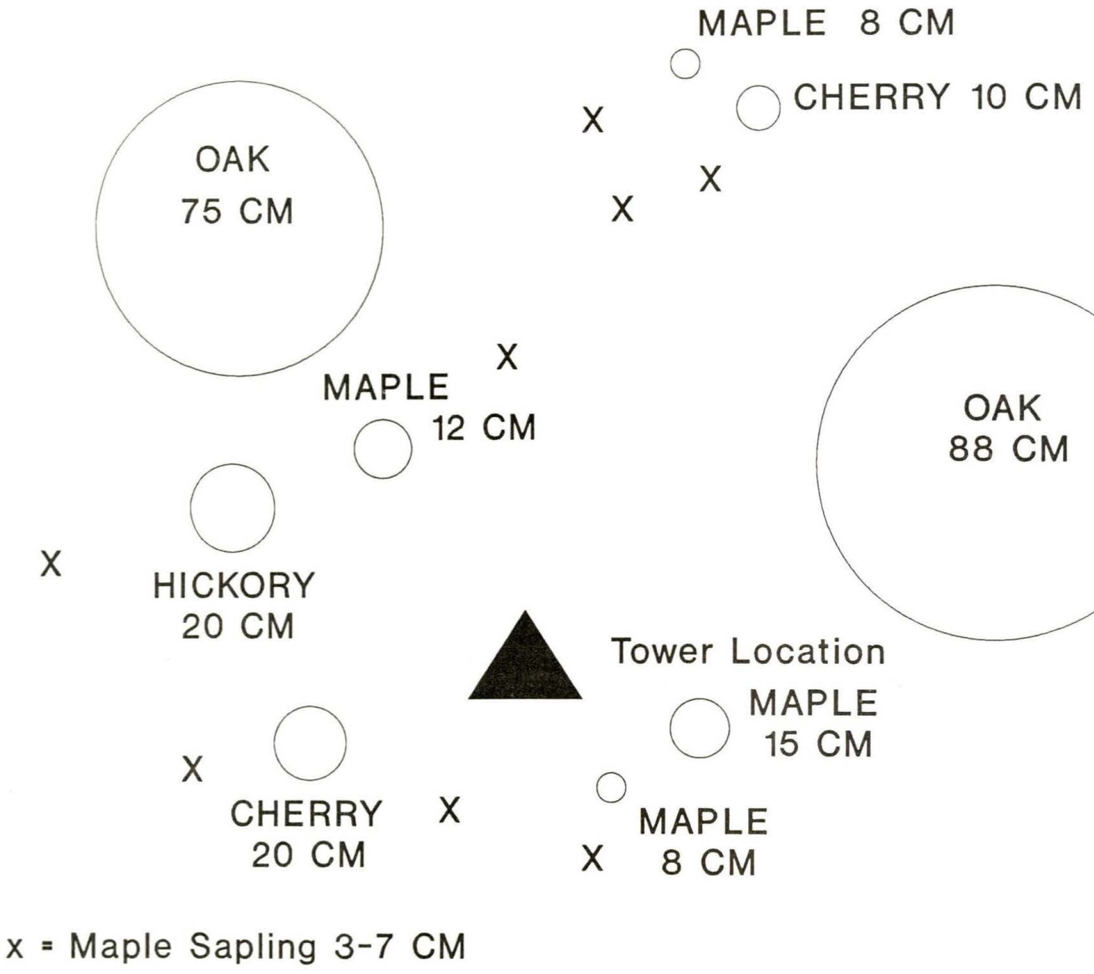

MAPLE 8 CM
CHERRY 10 CM
X
X
X
OAK
75 CM
X
MAPLE
12 CM
OAK
88 CM
X
HICKORY
20 CM
Tower Location
MAPLE
15 CM
X
CHERRY
20 CM
X
MAPLE
8 CM
X
x = Maple Sapling 3-7 CM

Figure 1.—Stem locations adjacent to a tower in continuous forest canopy in an old-growth forest in east-central Indiana.

As a preliminary comparison to guide future research, mid-growing season, mid-day measures of photosynthesis, transpiration, stomatal conductance, photosynthetically-active radiation, humidity, vapor pressure deficit, air temperature, and ambient carbon dioxide levels were taken for each crown intersection on each tower. Measurements were taken on one day, representative of a typical mid-growing season week in this part of the region. Additionally, ambient environmental measurements were taken at an open area on the gap tower (10 m) and at both locations at the forest floor (sunflecks). For each species-height measurement, three sample leaves were selected and physiological and environmental parameters noted above were measured simultaneously with an ADC LCA-3 portable infra-red gas analyzer (IRGA).

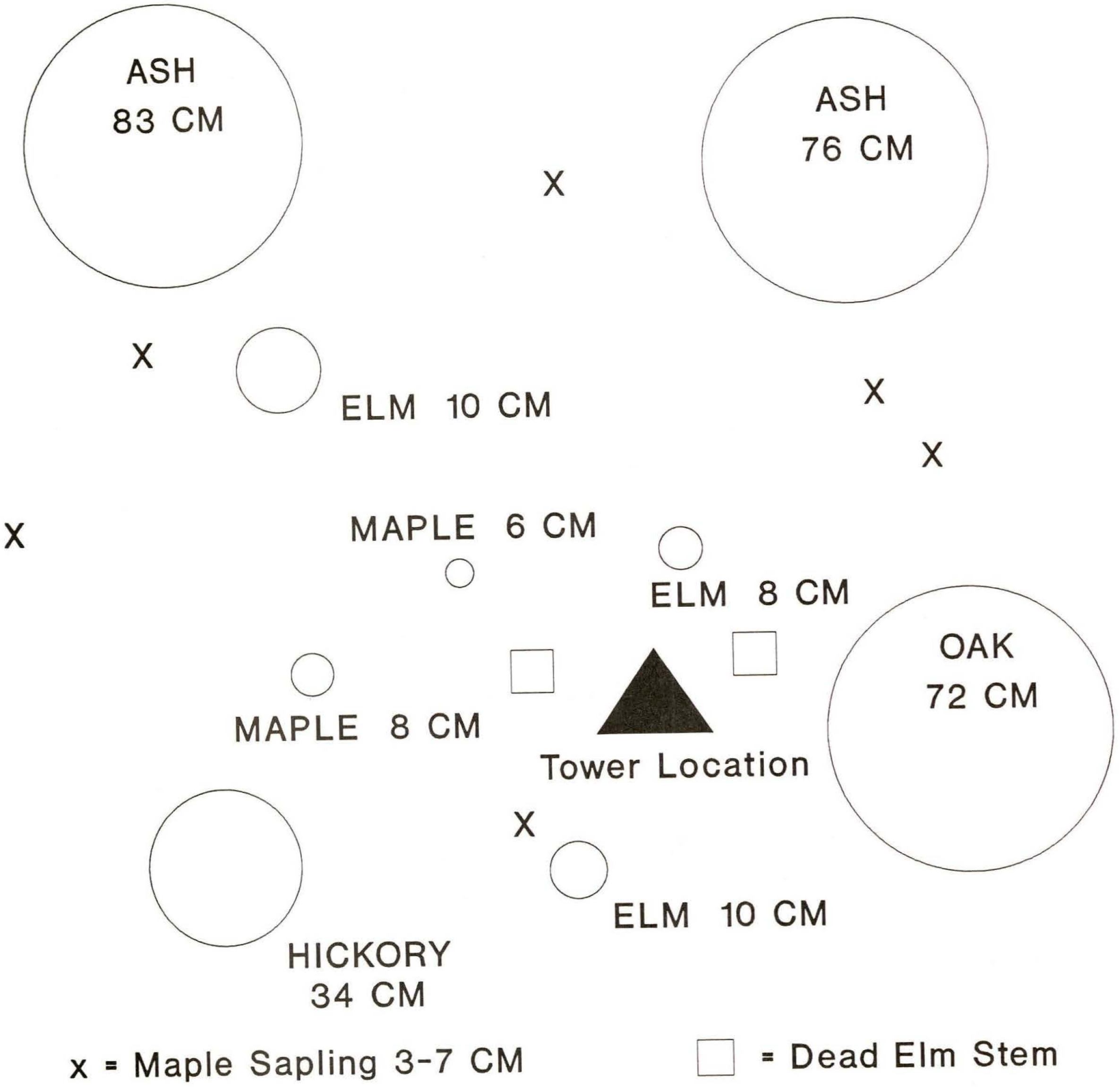

ASH
83 CM
ASH
76 CM
X
X
ELM 10 CM
X
X
X
MAPLE 6 CM
ELM 8 CM
OAK
72 CM
MAPLE 8 CM
Tower Location
X
ELM 10 CM
HICKORY
34 CM
x = Maple Sapling 3-7 CM
☐ = Dead Elm Stem

Figure 2.—Stem locations adjacent to a tower in a canopy gap in an old-growth forest in east-central Indiana.

RESULTS AND DISCUSSION

The microenvironmental gradient within the forest canopy is shown in Table 1. Though air temperature and vapor pressure deficit (VPD) were relatively constant from the forest floor to the top of the canopy at 30 m, this was not the case for humidity, ambient CO_2 concentrations, or light flux. As would be expected, light levels dropped very quickly with increasing depth within the canopy. Values near full sunlight dropped to near zero underneath the main canopy composed of old-growth shumard oak and shagbark hickory stems, approximately 10 m from the top of the canopy (20 m from the forest floor). Both humidity and CO_2 concentration increased with depth, being greatest near the forest floor. The humidity and VPD gradients represented only a few percent or kPa, respectively. The CO_2 gradient was substantial, with large concentrations at the top and at the bottom of the canopy. Concentrations at the forest floor were 20% greater than ambient concentrations in the main crown. Similar microenvironmental gradients have been shown for other mixed hardwood forest canopies (oak-hornbeam: Elias et al., 1989; oak-maple: Reich et al., 1990).

The physiological parameters are closely coupled with light flux (incident radiation) in this canopy (Table 1). Rates of photosynthesis, transpiration, and stomatal conductance are greatest at the top of the canopy where incident radiation is greatest. All parameters decrease below the main canopy, where light intensity is much reduced. In this environment, sunflecks become important for carbon assimilation during different periods of the day and growing season. Measured sunfleck values greatly exceed ambient light conditions at the forest floor (Table 1). At such low levels of light, there is very little herbaceous understory and few seedlings. The understory of saplings is composed only of sugar maple, a species able to photosynthesize at these low light levels. These physiological parameter gradients are also characteristic of mature, mixed-hardwood forests where oak overstories are found above more shade-tolerant species (Reich et al., 1990; Marek et al., 1989).

Thus, the microenvironment and physiology of old-growth oak-hickory-maple stands is similar to that of mature, second-growth stands. However, unlike these even-aged second-growth stands, old-growth canopies are not uniform (Parker, 1989), and mortality causes gaps in the overstory canopy. These gaps change the canopy structure and subsequent microenvironment found in old-growth forests. Microenvironmental parameters for the gap in the old-growth canopy are given in Table 2. Again, the air temperature and VPD are fairly stable from the top of the canopy at 30 m to the forest floor. In contrast to the situation in a closed canopy, humidity and CO_2 concentrations show only small gradients, again being greatest near the forest floor. Without tree cover in the gap (except near the forest floor), the flux of water vapor and CO_2 are relatively unaffected. Light, however, shows significant change as one would expect. Significant levels of light reach to the canopy of the sugar maple regeneration at the bottom of the gap, approximately 26 m from the top of the surrounding old-growth (4 m from the forest floor). And light below this height is equivalent to light levels below the main old-growth canopy of the closed-canopy tower location (Table 1). The result of this is significant rates of physiological activity low in the forest relative to the same height under closed canopy (Table 2). Photosynthesis of sugar maple and elm regeneration allows steady growth toward the main canopy (at least until disease removes the elms as has happened at about 7 m). Though oak seed is plentiful in this forest, oak is a very minor constituent of gap regeneration (Parker and Sherwood, 1986). The ability of maple and elm to photosynthesize at the low light levels of the forest floor probably allows establishment before gaps occur, providing an advantage over oak seedlings. As gaps do occur, these tolerant species would pre-empt the space that oak seedlings would need to respond to the significant addition of light near the forest floor. Of more importance is the effect of introduced light on photosynthesis of crowns at intermediate levels in the canopy that constitute the edges of the gap. Appreciable rates of photosynthesis (about 7 umol $m^{-2}s^{-1}$) are occurring in this gap from 4 m to 20 m for edge trees (Table 2). There is also the question of enhanced light effects on the productivity and dynamics of species adjacent to, but not immediately bordering, the canopy gap. Again, sunflecks can play an important role. This

Table 1.—Microenvironmental and physiological parameters measured along a canopy height profile in closed canopy in an east-central Indiana old-growth forest. Values are means (standard deviations) of three measurements.

Species	Height	Ambient CO$_2$ concentration	Humidity	Vapor pressure deficit	Light flux density	Air temperature	Net Photo-synthesis	Leaf transpiration & conductance	
	(m)	(ppm)	(%)	(kPa)	(umol/m^2/s)	(^{o}C)	(umol/m^2/s)	(mmol/m^2/s)	
Shumard oak	30	361 (4.7)	51.9 (0.6)	2.1 (0.0)	958 (651)	30.6 (0.1)	12.3 (5.0)	3.5 (0.8)	369.1 (158.0)
Black cherry	24	333 (0.6)	50.1 (0.0)	2.4 (0.0)	718 (521)	31.8 (0.0)	6.8 (3.4)	2.0 (1.0)	126.6 (76.0)
Shagbark hickory	20	331 (0.6)	50.4 (0.0)	2.3 (0.0)	207 (168)	31.7 (0.1)	3.7 (1.2)	1.5 (0.2)	80.5 (15.2)
Sugar maple	20	330 (0.0)	50.1 (0.6)	2.4 (0.0)	475 (222)	31.8 (0.1)	6.8 (2.5)	2.3 (0.6)	148.5 (55.7)
Sugar maple	18	329 (0.5)	51.0 (0.6)	2.3 (0.0)	54 (19)	31.5 (0.1)	1.5 (0.8)	1.1 (0.1)	59.5 (8.1)
Sugar maple	18	328 (0.0)	51.0 (0.0)	2.2 (0.0)	40 (19)	31.2 (0.1)	1.2 (0.5)	1.1 (0.2)	57.3 (13.4)
Sugar maple	15	327 (0.0)	51.0 (0.0)	2.2 (0.0)	27 (6)	31.1 (0.1)	0.9 (0.3)	0.9 (0.1)	45.7 (4.8)
Sugar maple	12	329 (0.6)	51.7 (0.0)	2.2 (0.0)	16 (4)	30.9 (0.1)	0.7 (0.5)	0.7 (0.1)	37.6 (4.6)
Sugar maple	10	329 (0.7)	51.3 (0.0)	2.2 (0.0)	22 (3)	30.9 (0.1)	1.2 (0.4)	0.8 (0.1)	38.9 (5.6)
Sugar maple	5	345 (4.7)	52.3 (0.0)	2.1 (0.0)	9 (1)	30.4 (0.1)	0.8 (0.3)	0.6 (0.1)	30.6 (4.5)
Sugar maple	4	348 (0.6)	52.6 (0.0)	2.1 (0.0)	13 (2)	30.3 (0.0)	0.6 (0.3)	1.0 (0.1)	55.6 (5.2)
Sugar maple	2	376 (3.5)	54.8 (0.0)	1.9 (0.0)	10 (0)	29.7 (0.0)	0.2 (0.2)	0.9 (0.0)	56.9 (0.0)
Ambient	0	404	54.0	2.0	5*	30.0			

*Sunfleck = 896 umol/m^2/s

Table 2.—Microenvironmental and physiological parameters measured along a canopy height profile in a canopy gap in an east-central Indiana old-growth forest. Values are means (standard deviations) of three measurements.

Species	**Height**	**Ambient CO_2 concentration**	**Humidity**	**Vapor pressure deficit**	**Light flux density**	**Air temperature**	**Net Photo-synthesis**	**Leaf transpiration & conductance**	
	(m)	(ppm)	(%)	(kPa)	(umol/m^2/s)	(^{o}C)	(umol/m^2/s)	(mmol/m^2/s)	
Shumard oak	30	338 (2.3)	51.0 (1.8)	2.2 (0.1)	649 (306)	30.6 (0.6)	5.4 (2.4	1.5 (0.6)	96.1 (55.6)
Shagbark hickory	20	337 (0.6)	46.4 (0.6)	2.7 (0.1)	270 (17)	32.9 (0.3)	7.6 (1.6)	2.5 (0.4)	132.6 (22.3)
Ambient	10	336	50.0	2.3	226	31.6			
Sugar maple	4	346 (4.0)	51.4 (0.0)	2.2 (0.0)	406 (94)	30.8 (0.1)	7.1 (0.5)	1.8 (0.1)	115.3 (6.9)
Sugar maple	2	361 (4.0)	51.7 (0.0)	2.1 (0.0)	45 (15)	30.5 (0.1)	1.7 (0.3)	1.1 (0.1)	63.1 (5.3)
American elm	2	363 (1.7)	52.2 (0.6)	2.1 (0.0)	54 (12)*	30.0 (0.1)	2.1 (0.2)	1.3 (0.2)	77.2 (10.5)

*Sunfleck = 401 umol/m^2/s

is currently a point of controversy in the ecological literature (see e.g. Lieberman et al., 1989; Publicover and Vogt, 1991; Brokaw 1982). The effects of the canopy gaps in old-growth probably reach beyond the immediate opening. Light, in particular, probably impacts nearby seedlings and samplings (as measured by sunflecks, Table 1 & 2). Though not part of the current study these effects will be measured in future research. We speculate, however, that these gaps hasten the change to shade tolerant species, providing just enough light to accelerate growth of these species within the understories of the adjacent closed canopy areas.

The differences in architecture between closed-canopy forest and canopy gaps are evident. In old-growth forests, these differences are part of the process of mortality and tree replacement, unlike many even-aged, second-growth Central Hardwood stands. The effect of the different architectures is spatial variation (horizontal and vertical) in microenvironment and resulting physiology, ultimately affecting productivity and species dynamics. But these are the parameters we will change as we apply silvicultural techniques for uneven-aged management or management to mimic old-growth structure. From the present data we can see a change in the rate of important physiological processes at different canopy levels. Their implications for changing rates of ecological processes must be evaluated, and this is the focus of continuing research.

LITERATURE CITED

Botkin, D.B. 1990. Discordant Harmonies. Oxford University Press, Oxford, UK.

Brokaw, N.V.L. 1982. The definition of treefall gap and its effect on measures of forest dynamics. Biotropica 14:158-160.

Elias, P., I. Kratochvilova, D. Janous, M. Marek, and E. Masarovicova. 1989. Stand microclimate and physiological activity of tree leaves in an oak-hornbeam forest. I. Stand microclimate. Trees 4:227-233.

Homoya, M.A. D.B. Abrell, J.A. Aldrich, and T.W. Post. 1985. The natural regions of Indiana. IN Academy of Science 94:245-268.

Lieberman, M., D. Lieberman, and R. Peralta. 1989. Forests are not just swiss cheese: Canopy stereogeometry of non-gaps in tropical forests. Ecology 70:550-552.

Marek, M., E. Masarovicova, I. Kratochvilova, P. Elias, and D. Janous. 1989. Stand microclimate and physiological activity of tree leaves in an oak-hornbeam forest. II. Leaf photosynthetic activity. Trees 4:234-240.

Parker, G.R. 1989. Old-growth forests of the Central Hardwood Region. Natural Areas Journal 9:5-11.

Parker, G.R. and P.T. Sherwood. 1986. Gap phase dynamics of a mature Indiana forest. IN Academy of Sci. 95:217-223.

Parker, G.R., D.J. Leopold, and J.K. Eichenberger. 1985. Tree dynamics in an old-growth, deciduous forest. Forest Ecology and Management 11:31-57.

Prentice, B. 1927. Forest survey No. 1. Herbert Davis Forestry Farm. Unpublished report to the Department of Forestry and Conservation, Purdue University, West Lafayette, IN.

Publicover, D.A. and K.A. Vogt. 1991. Canopy stereogeometry of non-gaps in tropical forests - A comment. Ecology 72:1507-1510.

Reich, P.B., D.S. Ellsworth, B.D. Kloeppel, J.H. Fownes, and S.T. Gower. 1990. Vertical variation in canopy structure and CO_2 exchange of oak-maple forests: influence of ozone, nitrogen, and other factors on simulated canopy carbon gain. Tree Physiology 7:329-345.

Runkle, J.R. 1990. Gap dynamics in an Ohio *Acer-Fagus* forest and speculations on the geography of disturbance. Canadian Journal of Forest Research 20:632-641.

Runkle, J.R. 1991. Gap dynamics of old-growth eastern forests: Management implications. Natural Areas Journal 11:19-25.

Bark Thermal Properties of Selected Central Hardwood Species

Gretel E. Hengst and Jeffrey O. Dawson[1]

Abstract: Some physical, thermal, and chemical properties of bark of eleven tree species native to the central hardwood region were measured to determine their potential to protect the vascular cambium from damage by fire. The relationship between dbh and bark thickness for each of sixteen species was determined. For purposes of monitoring seasonal trends, two species (Quercus macrocarpa Michx. and Acer saccharinum L.) were sampled periodically during one growing season. Heat transfer through bark tissue of eleven species was monitored during simulated fires conducted in the field. Bark samples were analyzed for moisture content, specific gravity, dry weight, and time until ignition, and subjected to standard test methods for determination of volatile matter content. Overall, heat flux and maximal cambial temperatures during simulated fires were reduced as bark thickness increased. Thick-barked species had lower maximal temperatures, longer times to reach peak temperatures, slower rates of heat loss, and shorter time until surface ignition. Populus deltoides Marsh. was the most fire resistant among species tested, while Acer saccharinum was the least. Specific gravity was positively correlated with thermal conductivity and likely influenced the rate at which cambial temperatures rose as well as the time required for surface ignition. Moisture content was lower in thin-barked species with higher specific gravities.

INTRODUCTION

A fundamental assumption of fire ecology is that fire in the natural landscape is neither inherently destructive nor constructive; it merely brings about change. Historically fire has been considered by foresters to be undesirable in the central hardwood region of North America due to its damaging effect on hardwoods with high veneer and sawlog values. However, prescribed burns are becoming increasingly commonplace as resource managers learn the values of periodic fires to supplement natural processes (Wade and Lunsford 1989). The replacement of early-to-mid-successional *Quercus* species as the predominant constituents of eastern hardwood forests by the more shade-tolerance, mid-to-late-successional *Acer* species may be the result of a reduced fire frequency policy (Wuenscher and Valiunas 1967, Grimm 1983, Nigh et al. 1985, Abrams 1986). The transition of *Quercus* species to later successional species will likely continue without control of competing species (Abrams and Scott 1989). Reduced survival and reproduction of mesic *Acer* species to fire and the relative fire resistance of many central North American *Quercus* species (Reich et al. 1990) suggest that the current transitional trend may be reversed through use of prescribed burns .

Alternate methods of vegetation management such as herbicide application and mechanical control are high in cost relative to prescribed burning. However, without a thorough understanding of the effects of fire on hardwood species, prescribed burns cannot be used to achieve a predictable outcome (Green and Shilling 1987).

Little is known about the fire tolerance of central hardwoods. Our study objectives were to obtain empirical information on physical and thermal properties of bark of several native tree species, and to establish relationships among properties indicative of fire tolerance and critical heat levels of vascular cambial tissue of trees exposed to fire. The research concentrated on two questions:

---

[1] Department of Forestry, University of Illinois at Urbana-Champaign.

1) Do thermal characteristics of bark differ among species?
2) Do physical and chemical properties of bark relate to a species' fire tolerance?

MATERIALS AND METHODS

Study sites

The trees studied were located in the Illini Forest Plantations (40°04'N Lat., 88°12'W Long.), Brownfield Woods (40°09'N Lat., 88°10'W Long.), and Trelease Woods (40°09'N Lat., 88°09'W Long.), all located near Urbana, Illinois, and Robert Allerton Park (39°59'N Lat., 88°39'W Long.), near Monticello, Illinois. In addition, trees located in Forest Glen County Preserve (41°59'N Lat., 87°45'W Long.), near Georgetown, Illinois, and Kennekuk Cove County Park (40°10'N Lat., 87°45'W Long.), near Danville, Illinois, were studied. The Illini Forest Plantations contain plantings of hardwood and softwood species approximately 40 years old *Prunus serotina* Ehrh., is a volunteer species in the Illini Forest Plantations and younger than the other trees measured. Plant communities at the other sites were representative of common mesophytic forest types of the Midwest, and are dominated by *Acer saccharum* Marsh. replacing for dominant *Quercus* species.

DBH and Bark Thickness Measurements

As bark thickness is a commonly used indicator of fire tolerance (Starker 1934, Hare 1961, Spalt and Reifsnyder 1962, Hare 1965, Vines 1968, Uhl and Kauffman 1990), measurements of dbh (diameter at breast height of 1.4 m) and bark thickness were made of sixteen upland and lowland species at all the locations listed above to determine the relationship of the two values across several age, site, and size categories. The species examined were *Acer saccharinum* L. (silver maple), *Acer saccharum* Marsh. (sugar maple), *Fraxinus americana* L. (white ash), *Juglans nigra* L. (black walnut), *Liquidambar styraciflua* L. (sweetgum), *Liriodendron tulipifera* L. (tulip-poplar), *Platanus occidentalis* L. (sycamore), *Populus deltoides* Marsh. (eastern cottonwood), *Prunus serotina* Ehrh. (black cherry), *Quercus alba* L. (white oak), *Quercus imbricaria* Michx. (shingle oak), *Quercus macrocarpa* Michx. (bur oak), *Quercus muehlenbergii* Engelm. (chinkapin oak), *Quercus rubra* L. (red oak), *Tilia americana* L. (American basswood), and *Pinus strobus* L. (Eastern white pine). Bark thickness on each of these trees was made with a standard bark gauge and recorded to the nearest mm. Measurements were made 1.3 m above ground level on the north and south sides of each tree. Diameters were determined to the nearest mm.

Determination of Bark Physical Properties

Bark samples were collected from three randomly-selected trees of each of the following eleven study species grown in single-species plots of approximately 0.4 ha each at the Illini Forest Plantations, where destructive sampling was permissible: *A. saccharinum*, *F. americana*, *J. nigra*, *L. styraciflua*, *L. tulipifera*, *P. occidentalis*, *P. deltoides*, *P. serotina*, *Q. macrocarpa*, *T. americana*, and *P. strobus*. In this study bark is defined as all tissues located outside the vascular cambium. Samples were taken from the same plots of the eleven species of similar-aged trees that were subjected to fire treatments. Trees with apparent mechanical injury or disease were excluded from sampling. Dbh and bark thickness were measured and recorded from each sample tree. Bark samples were 5 x 5 cm in size and removed from the north and south sides of each of three trees per species. Only trees in the plot interiors were sampled. Samples were taken at 1.5 m height and were removed by cutting through the bark with a chisel. Preliminary measurements of the trees under study showed bark thickness to be the same at that height as within 50 cm of the soil, where ground fires would likely impact trees. Samples were taken from all species on July 22, 1992, while samples of two species, *Q. macrocarpa* and *A. saccharinum*, were also obtained from different trees in the same plots on April 21 and October 21, 1992 for seasonal comparisons. Samples were sealed immediately in airtight plastic bags and stored frozen for laboratory analysis.

Moisture content, specific gravity, percentage volatile matter, and time till ignition were ascertained in the laboratory from the bark samples. Six samples per species (two per tree) were tested. Samples were placed in a drying oven for 96 hours at 64°C to achieve a uniform moisture level. Comparisons of field and oven-dry weights were then made to determine moisture content on a dry mass basis (% moisture = [field mass - oven-dry mass] / [oven-dry mass] X 100). Volume was measured by the mass displacement method and used to calculate bark specific gravity (g/cm3). Thermal conductivity (k) of bark of each species was calculated using the following formula: k = (4.684r + .076) x 10-4 cal/cm/sec°C (r is bark density, g/cm3) (Wenger 1984). After setting aside one quarter of each sample for ignition comparisons, remaining portions were ground to pass through a 20 mesh screen and dried for volatile matter analysis according to test methods described in the American Society for Testing and Materials designation D1762-84 (ASTM 1992). Crucibles containing one g of ground sample were each heated in a muffle furnace to 500°C. Percentage of volatile matter in each sample was determined from weight loss after heating. Comparisons of time until ignition of bark chunks were made at 300°C and 600°C. Chunks of consistent weight (1.35 g) were oven-dried. The door on the muffle furnace used in the ignition tests was left partially open to allow sufficient oxygen to reach the samples so that combustion could occur. An additional thermocouple probe was positioned next to the sample in the furnace to measure temperature levels at time of ignition. For this study, ignition was the instant at which glowing was observed on the surface of each bark sample.

Fire Simulations

Heat transfer through bark tissues was measured in the field using a modified wick-fire technique (Hare 1965, Uhl and Kauffman 1990). This method has been shown to create a heat pulse similar to that found in natural fires. A 1.5-cm diameter cotton rope soaked in kerosene provided the fuel for the fire simulation. The rope, in lengths one-half the diameter of each tree, was centered and attached 10 cm below the tip of a MgO-filled Inconel 600 sheath thermocouple probe (Inconel Corporation, Forestry Suppliers, Inc., Jackson, MS) inserted between the bark and the cambium. Because the trees subjected to fire simulations were of different diameters, these varying lengths of rope allowed for uniformity of heat levels per unit surface area. The flexible high temperature probe was positioned for the purpose of measuring cambial temperatures during the fire by inserting the tip 10 cm downward under the bark through the gap left by removal of a bark sample. A second thermocouple was positioned on the bark surface directly opposite the inserted probe. All burns were conducted on the north side of each tree to eliminate possible temperature influence by solar heating. Immediately before each burn, ambient air and cambial temperatures were recorded. Temperatures were recorded every ten seconds after ignition of the fuel source, until external bark temperatures stabilized at or near ambient levels.

Statistical Analyses

Linear regression analysis was used to compare dbh and bark thickness variables. The linear method provided better correlation coefficient values than did nonlinear methods. One-way ANOVA for the species and Duncan's Multiple Range test was applied to bark variables. A Pearson correlation matrix was used to determine correlations among values of bark properties. Methods used are described in **SAS User's Guide: Basics** and **SAS User's Guide: Statistics**, version 5 editions (SAS Institute Inc., Cary, NC).

RESULTS AND DISCUSSION

DBH and Bark Thickness Measurements

P. deltoides and *Q. macrocarpa* had significantly higher dbh values and bark thickness than the other fourteen species. Regression analyses from the data indicate a strong relationship of bark thickness and dbh for most species measured (Figures 1-16). The rate of increase between bark

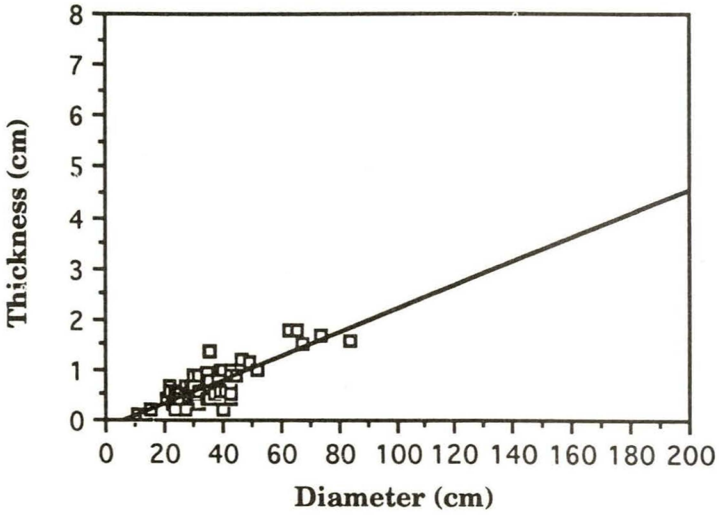


Figure 1.—Bark thickness vs. dbh for *Acer saccharinum*.

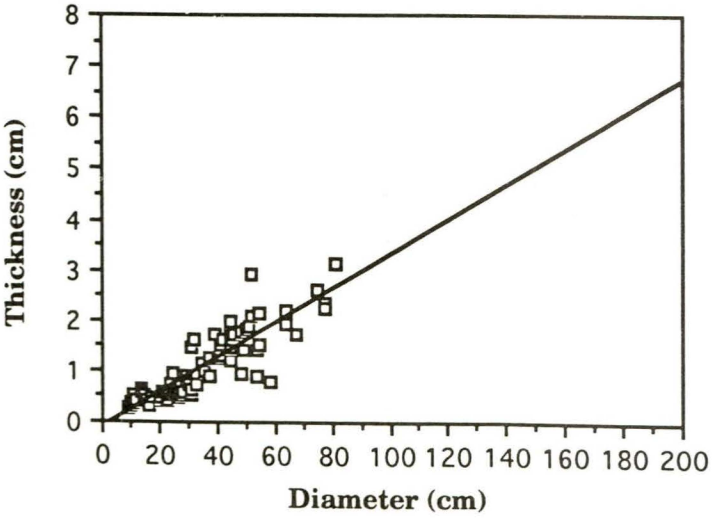


Figure 2.—Bark thickness vs. dbh for *Acer saccharum*.

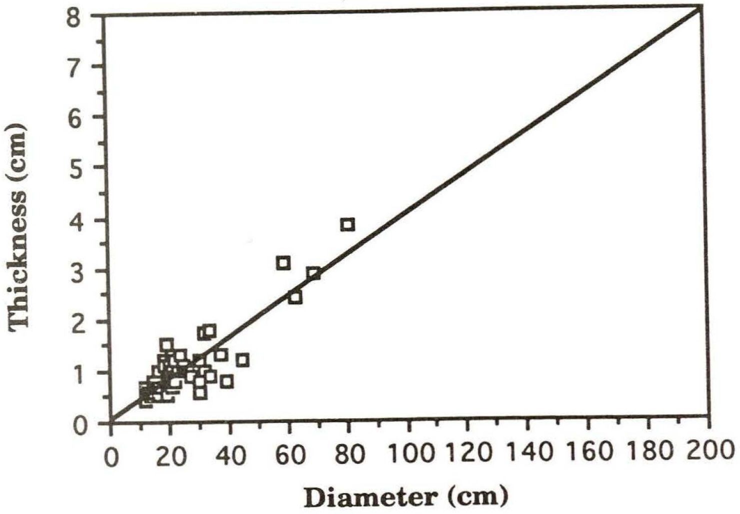


Figure 3.—Bark thickness vs. dbh for *Fraxinus americana.*

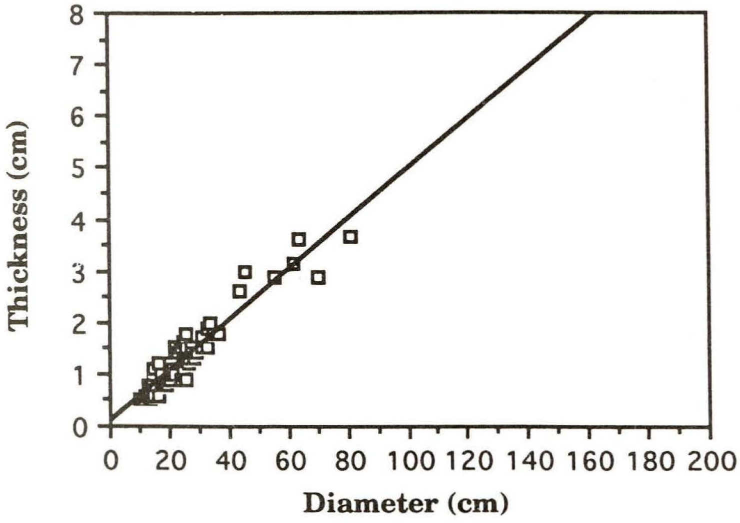


Figure 4.—Bark thickness vs. dbh for *Juglans nigra.*

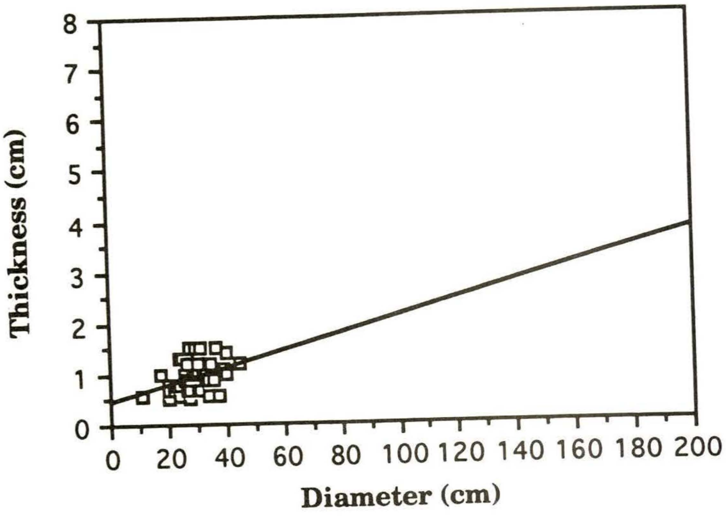


Figure 5.—Bark thickness vs. dbh for *Liquidambar styraciflua.*

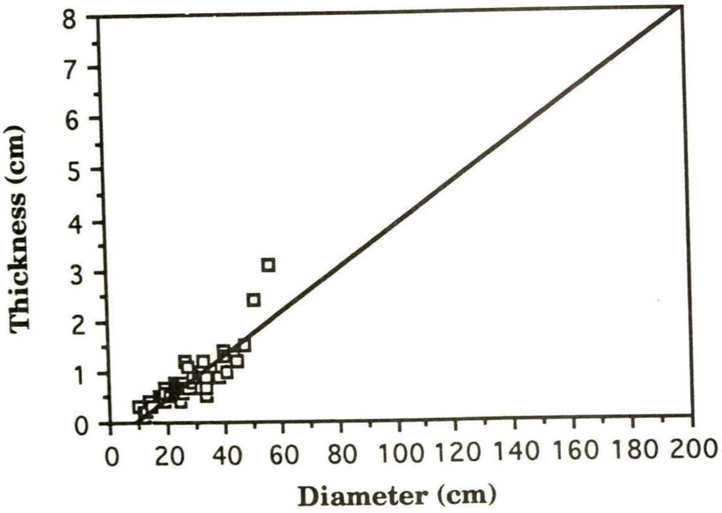


Figure 6.—Bark thickness vs. dbh for *Liriodendron tulipifera.*

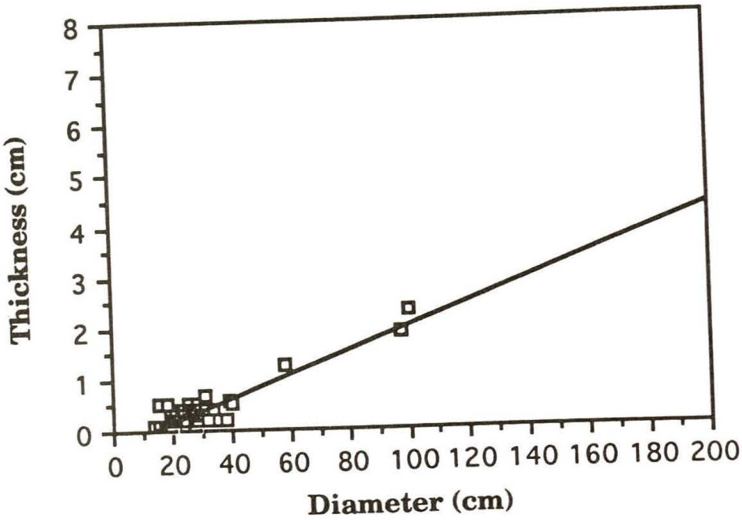


Figure 7.—Bark thickness vs. dbh for *Platanus occidentalis*.

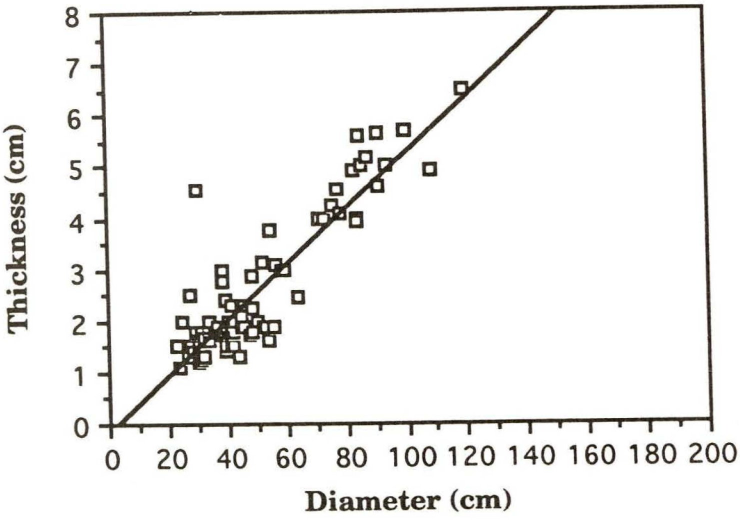


Figure 8.—Bark thickness vs. dbh for *Populus deltoides*.

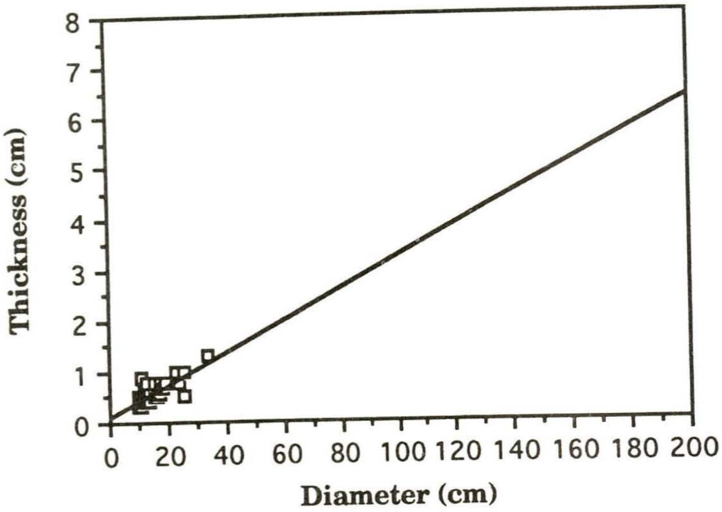


Figure 9.—Bark thickness vs. dbh for *Prunus serotina*.

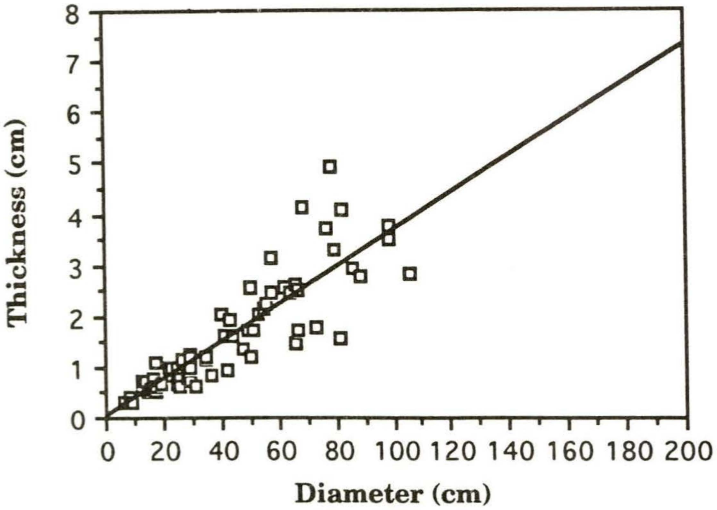


Figure 10.—Bark thickness vs. dbh for *Quercus alba*.

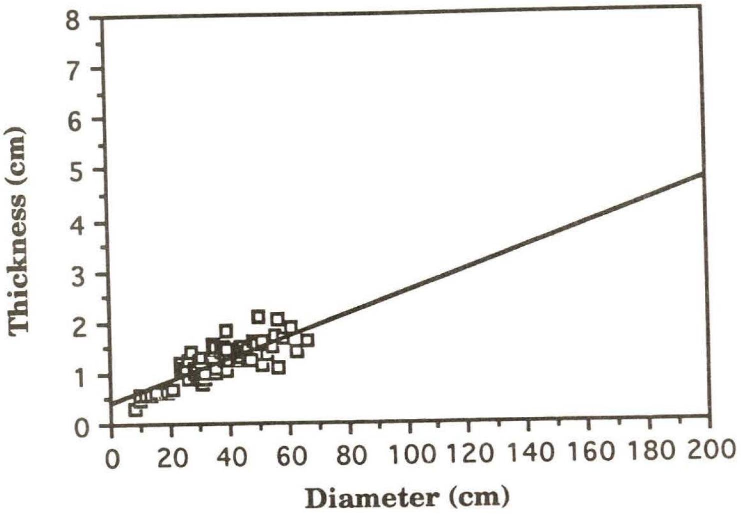


Figure 11.—Bark thickness vs. dbh for *Quercus imbricaria*.

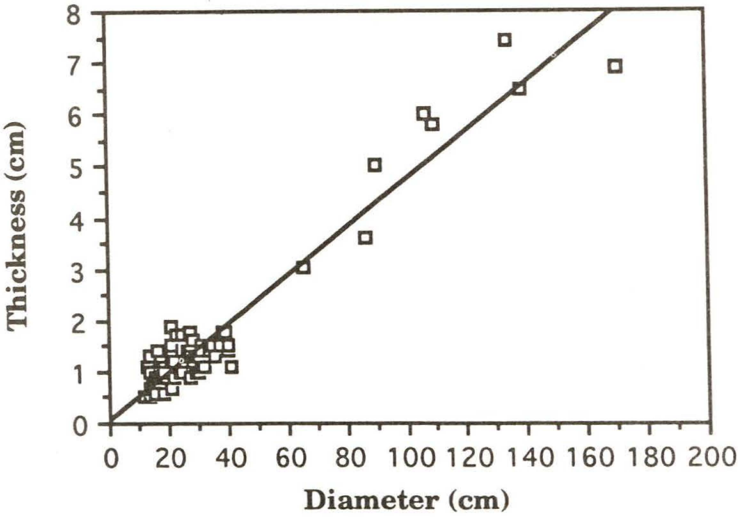


Figure 12.—Bark thickness vs. dbh for *Quercus macrocarpa*.

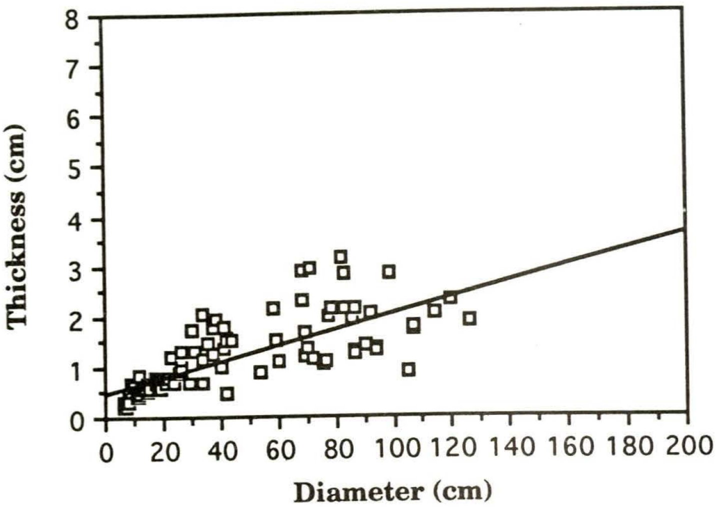


Figure 13.—Bark thickness vs. dbh for *Quercus muehlenbergii*.

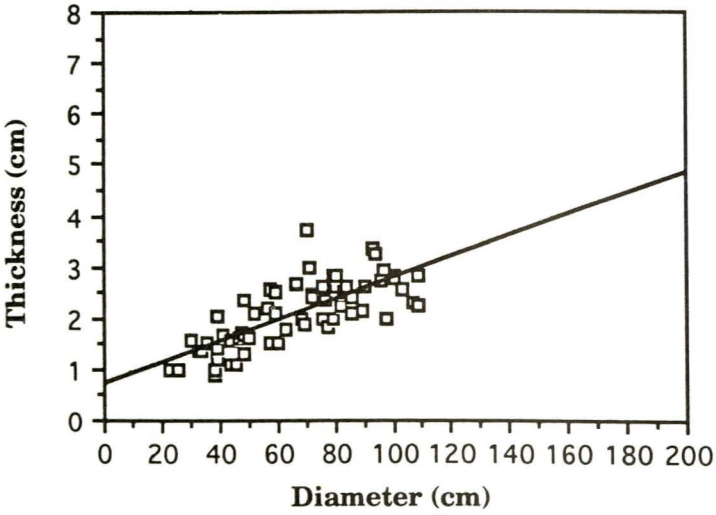


Figure 14.—Bark thickness vs. dbh for *Quercus rubra*.

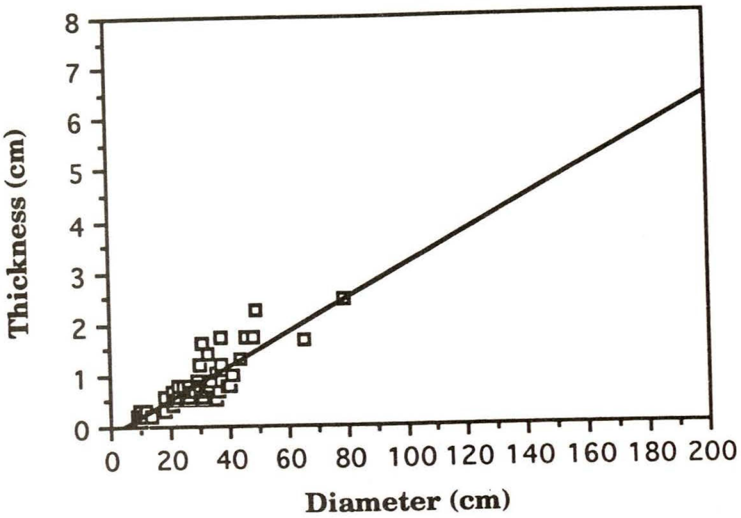


Figure 15.—Bark thickness vs. dbh for *Tilia americana*.

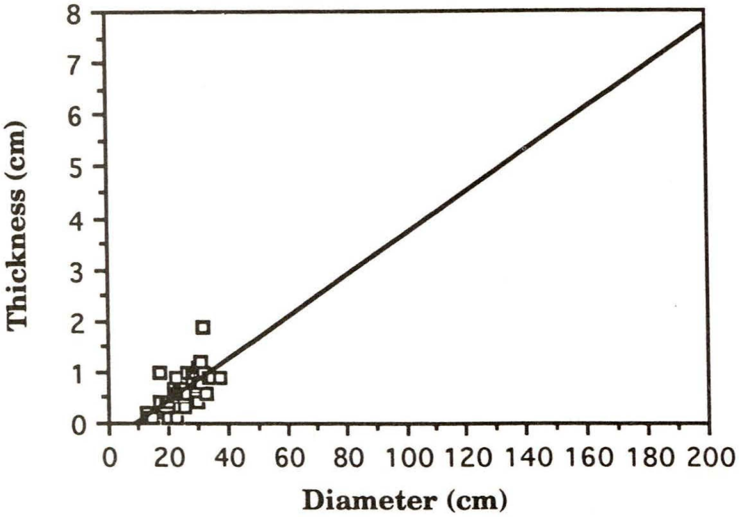


Figure 16.—Bark thickness vs. dbh for *Pinus strobus*.

Table 1.—Linear regression equations and correlation coefficients of bark thickness as a function of dbh for sixteen native tree species.

Tree species	**Regression equation (y = mx + b)**	r^2	**No. of trees measured**
Acer saccharinum	y = 0.0237x - 0.1529	0.66	63
Acer saccharum	y = 0.0343x - 0.1290	0.76	74
Fraxinus americana	y = 0.0395x + 0.0680	0.78	54
Juglans nigra	y = 0.0487x + 0.0962	0.89	63
Liquidambar styraciflua	y = 0.0163x + 0.4780	0.14	50
Liriodendron tulipifera	y = 0.0419x - 0.3558	0.74	52
Platanus occidentalis	y = 0.0229x - 0.2982	0.84	53
Populus deltoides	y = 0.0540x - 0.1568	0.85	85
Prunus serotina	y = 0.0310x + 0.1295	0.57	53
Quercus alba	y = 0.0367x + 0.0277	0.76	71
Quercus imbricaria	y = 0.0215x + 0.4410	0.63	69
Quercus macrocarpa	y = 0.0466x + 0.0705	0.93	64
Quercus muehlenbergii	y = 0.0157x + 0.4954	0.56	100
Quercus rubra	y = 0.0206x + 0.7198	0.56	64
Tilia americana	y = .0326x - 0.1708	0.70	59
Pinus strobus	y = 0.0405x - 0.3682	0.59	52

thickness with increasing stem diameter was greatest for *Q. macrocarpa* and least for *L. styraciflua* (Table 1 and Figures 1-16). The ranking of oaks in order of the rate of increase of bark thickness with radial growth of stem is *Q. macrocarpa* > *Q. alba* > *Q. inbricaria* > *Q. rubra* > *Q. muehlenbergii*. *Q. imbricaria* and *Q. rubra* are members of the red oak group and have lower rankings than two drier species in the white oak group. However, these members of the red oak group typically have faster growth rates than the other oaks in this study. *Q. rubra* is more mesic, has shallower roots, and requires better site conditions than other central North American oaks (Burns and Honkala 1990). The slope for *Q. muehlenbergii* (Table 1 and Figure 13) was the lowest among the species under study due to prevalence of the nonparasitic smooth patch fungus (*Aleurodiscus oakesii*) found on the bark. Smooth patch disease reduces bark thickness primarily of members of the white oak family. All but the youngest individuals of *Q. muehlenbergii* were affected. Such common occurence of the disease did not appear to affect the general health of the trees. However, protection from fire would likely be decreased due to the reduction of bark thickness. Table 2 shows the maximum bark thickness values found for each of the sixteen species. The largest individual trees examined in this study were *Q. macrocarpa* (134 cm maximum dbh). Upland species had proportionately greater bark thickness in relation to dbh in comparison with bottomland species, with the exception of the predominantly riparian *P. deltoides*.

Fire Simulations

Bark tissue can protect the vascular cambium from damage by fire. Overall trends show greater cambium protection with an increase in bark thickness (Figure 17). Maximum mean temperature of the cambium during fire simulation in planted trees of similar age ranged from 107.5°C (225.5°F) in *A. saccharinum* with thin bark (7.2 mm) to 50.4°C (122.7°C) in *P. deltoides* with thick bark (26.2 mm). Figure 18 illustrates the difference between internal and external temperature

Table 2.—Maximum bark thicknesses and corresponding dbh found in a sampling of native central hardwood species. For any species a minimum of 50 and a maximum of 100 trees make up the population from which the maximum value was obtained. Maximum values are from trees at least 40 years old occuring in plantations and natural stands.

Tree species	Maximum bark thickness (cm)	Corresponding dbh (cm)	Maximum thickness/ maximum dbh %
Quercus macrocarpa	7.4	134.3	11.0
Populus deltoides	6.5	120.0	10.8
Quercus alba	4.2	68.2	12.3
Fraxinus americana	3.8	81.6	9.3
Quercus rubra	3.7	69.9	10.6
Juglans nigra	3.6	81.0	8.9
Quercus muehlenbergii	3.2	82.2	7.8
Acer saccharum	3.2	80.9	7.9
Liriodendron tulipifera	3.1	56.3	11.0
Tilia americana	2.4	79.7	6.0
Platanus occidentalis	2.3	100.3	4.6
Quercus imbricaria	2.1	50.2	8.4
Pinus strobus	1.9	31.6	12.0
Acer saccharinum	1.8	65.4	5.5
Liquidambar styraciflua	1.5	36.5	8.2
Prunus serotina	1.3	34.0	7.6

fluxes in the example of a small individual *Q. macrocarpa* tree during a simulated burn. Table 3 lists mean maximal cambial temperatures recorded during the simulated fires, as well as the time that the temperatures remained above 60°C. Exposure to at least 60°C for 60 seconds or longer generally causes death of vascular plant tissues (Wright and Bailey 1982). Because cambial temperatures in all individuals of six of the species subjected to burns remained above 60°C for greater than 70 seconds and for as long as 910 seconds, these six species would likely be killed or scarred by a fire of similar intensity to the artificial fire in this study (Table 3). Flame length during the fires reached a mean of 42 ± 2.8 cm, representing a surface fire of low intensity. An additional four species had only one or two individuals that sustained lethal temperatures. *P. deltoides* maintained maximal cambial temperatures below 60°C for all individuals. An increase in the number of individuals that sustained lethal temperatures corresponds with increases in maximum cambial temperatures and increases in mean time above 60°C.

During the burns, cambial temperatures tended to rise rapidly in thin-barked species, reaching maximum temperatures in six minutes or less. Tree species with thick bark had lower maximum cambial temperature, longer lag times until maximum temperatures were achieved, and slower rates of heat loss from the cambial region following temperature peaks.

Maximum external bark temperatures ranged widely among the species burned, regardless of the relative consistency of flame length found in the simulated fires (Table 3). This variability of temperatures suggests that external bark structure influences absorption of heat. Several species with smoother textured bark maintained lower peak temperatures than those with thicker, fissured

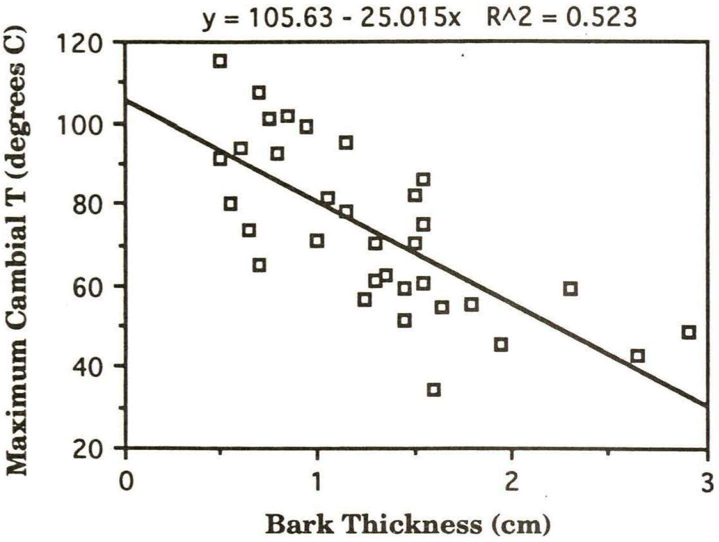


Figure 17.—The relationship between bark thickness and maximal cambial temperature for 33 individuals of 11 species during simulated fires.

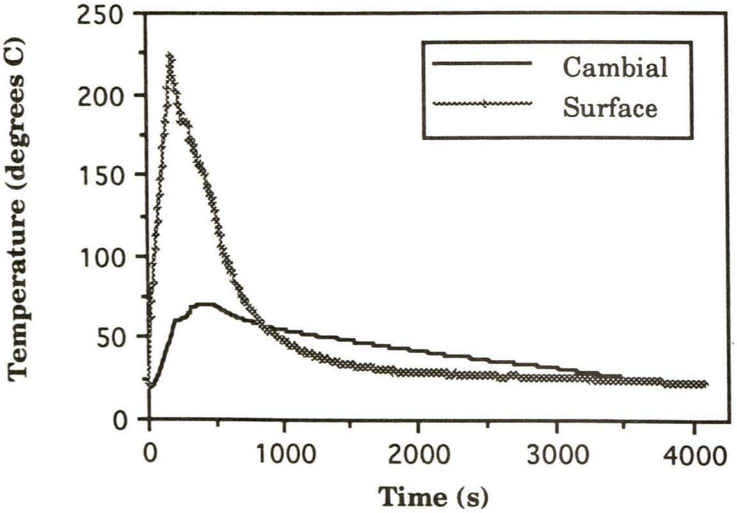


Figure 18.—Cambial and surface temperature fluxes for *Quercus macrocarpa* during a simulated fire.

Table 3.—Maximal cambial and bark surficial temperatures and duration of lethal cambial temperatures in relation to bark thickness of 40 year old trees subjected to simulated fire (n=3).

Tree species	Mean maximal cambial temperature (°C)	Mean cambial time above 60° (minutes)*	Mean bark thickness (cm)	Mean maximal external temp. (°C)
Populus deltoides	50.4	0	2.6	347.7
Pinus strobus	52.0	1.8 (1)	1.4	118.7
Quercus macrocarpa	57.1	3.1 (1)	1.5	267.1
Tilia americana	64.4	3.8 (1)	1.4	290.3
Juglans nigra	68.1	5.6 (2)	1.5	421.6
Prunus serotina	72.8	6.7 (3)	0.9	171.1
Liriodendron tulipifera	76.1	8.1 (3)	1.5	297.3
Fraxinus americana	78.4	7.8 (3)	1.2	321.1
Platanus occidentalis	81.8	9.0 (3)	0.6	202.1
Liquidambar styraciflua	98.8	13.3 (3)	0.7	275.6
Acer saccharinum	107.5	15.6 (3)	0.7	285.2

*Numbers in parentheses indicate the number of individuals per species burned that achieved an internal temperature above 60°C.

bark. The species that achieved the highest external temperature (*F. americana*, *J. nigra*, and *P. deltoides*) are also the species having bark that ignited during the burn. Some lower external temperature readings were probably caused by wind shifting flames away from the surface probe.

Determination of Bark Physical Properties

Among bark samples taken from the eleven species at the Illini Forest Plantations, analysis of variance yielded highly significant differences (p>0.01) among species for the ratio of dbh to bark thickness, moisture content, specific gravity, thermal conductivity, volatile matter content, time till 300°C ignition, and time till 600°C ignition (Table 4). Seasonal differences in bark moisture content of the two species were not statistically significant.

Table 4.—Analysis of variance for bark thickness/dbh ratio, percentage of moisture content, specific gravity, thermal conductivity, percentage of volatile matter, time till 300°C ignition, and time till 600°C. Number in brackets is the R2 value for the statistical model where significant at the 1% level.

Source of variation	Degrees of freedom	Mean squares for						
		Bark thick./ DBH	Moisture content %	Specific gravity (g/cm³)	[1]Thermal conoductivity	Volatile matter %	Time till 300°C ignition (s)	Time till 600°C ignition (s)
Species	10	0.0037 [.70]	0.1666 [.65]	0.0927 [.79]	1.7628 [.86]	0.0079 [.80]	1275.9485 [.83]	104.4455 [.79]
Error	55	0.0003	0.0164	0.0044	0.0503	0.0004	47.0818	4.9636

[1] 10-4 cal/cm/sec°C

P. deltoides bark proved to be far thicker than that of the other species of similar age in the Illini Forest Plantation plots. *P. deltoides* is a tree which grows more rapidly than the other species in this study, and whose bark is accordingly thicker because it has greater rates of bark thickening with radial stem growth (Figure 8). In fact the ratio of bark thickness to tree stem dbh and the rate at which bark thickness increases with increasing stem diameter for *P. deltoides* are relatively high among the tree species in this study. *P. serotina* was a volunteer species on the site and therefore had the smallest diameters and the thinnest bark. However, the bark thickness to dbh ratio for *P. serotina* was not the lowest among the species studied (Table 5). Bark thickness was found to be negatively correlated with both specific gravity and thermal conductivity (Table 6).

Moisture content and specific gravity may influence heat transfer to the cambium by bark (Hare 1965, Spalt and Reifsnyder 1962). Bark specific gravity, based on dry mass, showed a tendency toward higher values for species with thinner bark. Among the hardwood species in this study, *P. serotina*, *A. saccharinum*, and *P. occidentalis* had the highest values. *L. styraciflua*, *L. tulipifera*, and *P. deltoides* were low in specific gravity. Values for most of the species fell into ranges found in other studies (Martin and Crist 1968, Spalt and Reifsnyder 1962). Thermal conductivity correlated strongly with specific gravity for all species (Table 6). Specific gravity is a physical property to which other physical and mechanical properties can often be tied (Martin and Crist 1968).

Mean values for percent moisture content were generally lower for thin-bark species (Table 5). (The exception to this trend was *P. deltoides* with the thickest bark and lowest moisture concentration.) The larger proportion of outer bark to inner bark in this species may explain this low percentage. Moisture content of inner bark has been shown to be considerably higher than that of outer bark (Spalt and Reifsnyder 1962, Vines 1968). Therefore, the moisture content of thick-barked *P. deltoides* would be expected to be low with whole-bark analysis. *Q. macrocarpa* had an increase in bark moisture during July, followed by a drop in October (Table 7). This increase may be due to an abnormally rainy month combined with deeply furrowed texture which could easily trap and allow absorbtion of the large amount of rainfall. *A. saccharinum* had smoother bark and exhibited a reduction in moisture throughout the year, as expected. Overall, however, seasonal moisture differences were not significantly different.

The concentrations of volatile material in bark were highest for *L. tulipifera* and *T. americana* and lowest for *Q. macrocarpa*. The high percentage of volatile constituents in the samples might indicate that these barks are easily ignitable, but correlations between volatile matter and time till ignition were not strong (Table 6). Volatile content does not appear to explain differences in peak cambial temperatures during simulated fires nor the amount of time required to achieve ignition, nor did other bark values correlate strongly with volatile matter percentages (Table 6).

Ignition time comparisons revealed that an increase in time was needed for combustion in several species with thinner barks. These species had not only higher specific gravity values overall but also higher peak cambial temperatures. As a result, longer time required for ignition may be due to a more rapid passage of heat to the cambium layer and lower amounts of oxygen available in thinner, high specific gravity bark than in thick-barked species with lower densities. Because glowing combustion will not take place at the surface until temperatures reach 500° to 600°C (Chandler et al. 1983), quicker passage of heat through the bark from the heated surface would increase the time required to reach higher temperatures necessary for ignition. Species with lower thermal conductivity values would hold heat on the surface longer, reducing time until ignition.

SUMMARY AND CONCLUSIONS

The ability of bark to insulate the cambium from lethal temperatures produced by fire is evident in the results of this study. The efficiency of bark varied among species, with thick-barked hardwoods providing as much protection as the conifer *P. strobus*. Diameter of the tree as an indicator of fire resistance was dependent upon the rate of bark thickening with radial stem growth as well as the protective properties of the bark. Upland species tended to be in the high or intermediate

Table 5.—Midsummer bark properties (oven-dry weight basis) of eleven native tree species in a 40-year-old plantation. Means in a column followed by the same letter are not significantly different (a = 0.05).

Tree species	Bark thickness (cm)	Dbh (cm)	Bark thick./ dbh	Moisture content %	Specific[1] gravity (g/cm^3)	Thermal conductivity	Volatile matter %	Time till 300°C ignition (s)	Time till 600°C ignition (s)
Acer saccharinum	0.89de	34.47ab	5.16de	60.53de	0.71ab	3.45a	62.51cd	44b	16b
Fraxinus americana	1.27bcd	33.60ab	7.56bc	90.28b	0.48c	2.33cd	62.24cd	21d	10de
Juglans nigra	1.52b	26.27b	11.57a	81.31bc	0.44cd	2.12d	60.51d	22d	9e
Liquidambar styraciflua	1.10cde	32.17b	6.84bcd	78.74bc	0.44cd	2.13d	60.00d	27cd	5f
Liriodendron tulipifera	1.25bcd	31.90b	7.84bc	106.84a	0.50c	2.39cd	69.79a	32c	14bc
Platanus occidentalis	0.72e	33.00b	4.36e	69.75cd	0.63b	3.05b	61.31cd	49b	20a
Populus deltoides	2.45a	41.50a	11.81a	47.46e	0.45d	2.17d	63.04c	33c	9e
Prunus serotina	0.72e	15.67c	9.19b	62.99de	0.72a	3.45a	61.12cd	26cd	7ef
Quercus macrocarpa	1.36ab	33.57ab	8.10bc	84.69b	0.47c	2.30cd	55.43e	27cd	8e
Tilia americana	1.08cce	32.87b	6.57cd	86.54b	0.51c	2.47c	66.33b	23d	9e
Pinus strobus	0.78e	28.47b	5.48de	87.05b	0.69ab	3.32a	62.26cd	69a	12cd

---

[1] 10-4 cal/cm/sec°C

Table 6.—Pearson correlation coefficients for properties of eleven native hardwood species from a 40-year-old plantation (n=66).

Bark property	**Dbh**	**Bark thick**	**Bark thick./ dbh**	**Moisture content %**	**Specific gravity (g/cm^3)**	**[1]Thermal conduc- tivity**	**Volatile matter %**	**Time till 300°C ignition (s)**	**Time till 600°C ignition s)**
Dbh	1.0000	0.5949	-0.1164	-0.0705	-0.4303	-0.4071	-0.0127	-0.0241	0.1413
Bark thickness	0.5949	1.0000	0.7042	-0.2688	-0.6614	-0.6464	-0.0869	-0.3385	-0.2397
Bark thick./dbh ratio	-0.1164	0.7042	1.0000	-0.2889	-0.4622	-0.4747	-0.1417	-0.4487	-0.3926
Moisture content	-0.0705	-0.2688	-0.2889	1.0000	-0.1116	-0.2122	0.3680	-0.0640	-0.0415
Specific gravity	-0.4303	-0.6614	-0.4622	-0.1116	1.0000	0.9108	0.0447	0.4931	0.3320
Thermal conductivity	-0.4071	-0.6464	-0.4747	-0.2121	0.9108	1.0000	0.0684	0.5301	0.3861
Volatile matter	-0.0127	-0.0869	-0.1417	0.3680	0.0447	0.0684	1.0000	0.0503	0.1878
Time till 300°C ignition	-0.0241	-0.3385	-0.4487	-0.0640	0.4931	0.5301	0.0503	1.0000	0.5317
Time till 600°C ignition	0.1413	-0.2397	-0.3926	-0.0415	0.3320	0.3861	0.1878	0.5317	1.0000

[1] 10-4 cal/cm/sec°C

Table 7.—Seasonal values of bark properties (oven-dry weight basis) for 40-year-old trees of two species. Means in a column followed by the same letter are not significantly different (a = 0.05).

Tree species	**Bark thickness (cm)**	**Dbh (cm)**	**Bark thick./ dbh**	**Moisture content %**	**Specific gravity (g/cm^3)**	**[1]Thermal conductivity**	**Volatile matter %**
SPRING:							
Acer saccharinum	0.76b	37.33a	4.07b	68.82a	0.76a	3.64a	64.18a
Quercus macrocarpa	1.52a	33.37a	9.11a	62.20a	0.54b	2.59b	56.36b
SUMMER:							
Acer saccharinum	0.89b	34.47a	5.16b	60.53a	0.71a	3.45a	62.51a
Quercus macrocarpa	1.36a	33.57a	8.10a	84.69a	0.47b	2.30b	55.43b
FALL:							
Acer saccharinum	0.73b	34.07a	4.29b	55.90a	0.75a	3.59a	62.40a
Quercus macrocarpa	1.35a	32.53a	8.30a	53.19a	0.46b	2.21b	58.69b

[1] 10-4 cal/cm/sec°C

range for bark thickness to dbh ratios and rate of bark thickening with stem radial growth, while lowland hardwoods tended to have lower ratios.

Cambial temperatures continued to rise after flames went out and while surface temperatures began to drop. Thick-barked species did not reach maximal temperatures as high as those found in species with thin bark. Time required to reach peak temperatures and then return to ambient temperatures increased with bark thickness. *P. deltoides* was the most fire resistant among species of 40-year-old plantation trees tested, perhaps explaining its common presence along streams and minor drainages unprotected from fires in prairie regions of the central United States. *Q. macrocarpa* was also found to be highly fire resistant. *Q. macrocarpa* is a common tree of prairie savannahs, and one that must have been able to survive repeated exposure to intense fires in order to persist in prairie groves frequently exposed to fire. The relatively high resistance of *P. strobus* was expected, as the ability of many conifers occurring in regions with periodic fires to withstand burns is well documented. The high susceptibility of *A. saccharinum* to the heat of fire is consistent with its prevalence in low, moist sites in east central North America where fires probably occurred less frequently.

Specific gravity and thermal conductivity likely affect the amount of heat transmitted to the cambium as well as time required for the bark surface to reach ignition temperatures. Thin-barked species, with higher specific gravity and thermal conductivity values, increased in cambial temperature quickly, while taking longer to ignite. Thick-barked species required more time for heat transfer to the cambium and for cambial heat dissipation.

Considerable volatile material was present in bark samples of all species, but quantity of volatile material was not correlated with maximal cambial temperatures or time until ignition. Overall trends with moisture showed thin-barked species to have lower values. Seasonal testing of *Q. macrocarpa* and *A. saccharinum* revealed no statistically significant difference in seasonal moisture concentration of bark. Bark moisture concentration values were not significantly correlated with any of the thermal properties of bark measured.

Bark properties of hardwoods do exhibit different physical and chemical characteristics that influence the ability of trees to protect cambial tissues from high temperatures. Bark thickness is a good indicator of a tree's ability to protect its cambium from the lethal effects of fire. Thickness in combination with specific gravity strongly influence a tree's fire tolerance. Generally, upland hardwoods tend to produce thicker bark faster than lowland species. However, the bottomland species *P. deltoides* was an exception to this generalization. Both *P. deltoides* and *Q. macrocarpa* exhibit thick bark and relatively high rates of bark thickening with radial growth. These two species have broad ecological amplitudes with respect to substrate moisture and occur further to the west in drier, more fire-prone regions of North America than other eastern deciduous angiospermous trees.

LITERATURE CITED

Abrams, M.D. and M.L. Scott. 1989. Disturbance-mediated accelerated succession in two Michigan Forest Types. For. Sci. 35:42-49.

American Society for Testing and Materials (ASTM), 1992. Standard method for chemical analysis of wood charcoal. Designation: D1762-84 (Reapproved 1990). ASTM, Philadelphia, PA.

Burns, R.M. and B.H. Honkala. tech. coords. 1990. Silvics of North America: 2. Hardwoods. Agriculture Handbook 654. U.S. D.A. Forest Service, Washington, D.C., vol. 2, 877 p.

Chandler, C., P. Cheney, P. Thomas, L. Trabaud, and D. Williams. 1983. Fire in Forestry. Volume I. Forest Fire Behavior and Effects. John Wiley and Sons, New York, NY. 450 p.

Green, T. A. and C.L. Shilling. 1987. Predicting girdling probability for pine and hardwood saplings in low-intensity backfires. For. Sci. 33:1010-1021.

Grimm, E.C. 1983. Chronology and dynamics of vegetation change in the prairie-woodland region of southern Minnesota. New Phytologist 93:311-350.

Hare, R.C. 1961. Heat effects on living plants. U.S. For. Serv. So. For. Expt. Sta. Occas. Pap. 183. 32 p.

____ 1965. Contribution of bark to fire resistance of southern trees. J. For. 63:248-251.

Martin, R.E. and J.B. Crist. 1968. Selected physical-mechanical properties of eastern tree barks. For. Prod. J. 18:54-60.

Nigh, R.A., S.G. Pallardy, and H.E. Garrett. 1985. Sugar maple-environment relationships in the river hills of central Ozark Mountains of Missouri. Am. Mid. Nat. 114:235-251.

Reich, P.B., M.D. Abrams, D.S. Ellsworth, E.L. Kruger, T.J. Tabone. 1990. Fire affects ecophysiology and community dynamics of central Wisconsin oak forest regeneration. Ecology 71:2179-2190.

Spalt, K.W. and W.E. Reifsnyder. 1962. Bark characteristics and fire resistance: a literature review. U.S. For. Serv. So. For. Expt. Sta. Occas. Pap. 193. 19 p.

Starker, T.J. 1934. Fire resistance in the forest. J. For. 32:462-467.

Uhl, C. and J.B. Kauffman. 1990. Deforestation, fire susceptibility, and potential tree responses to fire in the eastern Amazon. Ecology 71:437-449.

Vines, R.G. 1968. Heat transfer through bark, and the resistance of trees to fire. Aust. J. Bot. 16:499-514.

Wade, D.D. and J.D. Lunsford. 1989. A guide for prescribed fire in southern forests. U.S.D.A. Forest Service, Southern Region Tech. Pub. R8-TP 11. February. Atlanta, GA. 56 p.

Wenger, K.F., editor. 1984. Forestry Handbook, Second Edition. John Wiley and Sons, New York, NY. 1335 p.

Wuenscher, J.E. and A.J. Valiunas. 1967. Presettlement forest compostion of the River Hills Region of Missouri. Am. Mid. Nat. 78:487-495.

Eco-physiology of *Acer saccharum* Trees on Glade-like Sites in Central Missouri

Eric J. Rhodenbaugh and Stephen G. Pallardy[1]

Abstract: Although sugar maple (*Acer saccharum* Marsh.) is not considered drought tolerant, it is common on xeric limestone glade-like sites in central Missouri. *Acer saccharum* on such sites may be a drought-tolerant ecotype or may have access to deep water supply through bedrock cracks. We investigated these possibilities during the 1990 growing season by comparing water relations and photosynthetic rates of *A. saccharum* trees growing on glade-like and typical upland sites.

Late-summer drought caused reductions in pre-dawn leaf water potential, but there were no significant differences in this parameter between trees growing on the two sites, nor were there differences in patterns of diurnal Ψ_l. Net photosynthetic rate (P_{net}) did not differ between sites either under dry or moist soil conditions. Regression analysis of responses of P_{net} and several environmental factors revealed no differences that would indicate differential physiological adaptation of trees between sites. It is most likely that *A. saccharum* trees growing on glade-like sites have access to deep water and are not a drought-tolerant ecotype.

Sugar maple (*Acer saccharum* Marsh.) is becoming an increasingly important species in the oak-hickory forests of Missouri (Nigh et al. 1985, Pallardy et al. 1988). Studies over the last 20 years have shown that oak species are regenerating poorly and that *A. saccharum* is now entering large sapling and small tree strata in many stands (Rochow 1972, Nigh et al. 1985, Pallardy et al. 1988).

The success of *A. saccharum* over *Quercus* spp. is due in large degree to the former's superior shade tolerance, i.e., its ability to survive better than species such as black oak (*Quercus velutina* Lam.), northern red oak (*Q. rubra* L.) and white oak (*Q. alba* L.) under low light conditions until an opening in the canopy occurs (Hinckley et al. 1978, Weber et al. 1985). Hett and Loucks (1971) reported that *A. saccharum* seedlings could survive, at a low rate of growth, for 10 or more years in the forest understory where light intensity generally was low. The ability of understory *A. saccharum* to utilize low light levels was further demonstrated by Weber et al. (1985). In this study, it was reported that up to 65 percent of the net carbon gain in this species occurred when photosynthetic photon flux density (PPFD) was between 50 and 100 $\mu mol \cdot m^{-2} \cdot s^{-1}$.

Success of *A. saccharum* may be hampered by its relatively low drought tolerance, particularly in cases where trees achieve canopy status on drier sites, a situation in which transpirational demand would be substantially greater. *Acer saccharum* is considered less drought tolerant than the four oak species previously mentioned (Hinckley et al. 1978, Hinckley et al. 1979, Bahari et al. 1985). However, paradoxically, *Acer saccharum* is common on xeric glade-like sites in central Missouri (Rochow 1972, Nigh et al. 1985, Pallardy et al. 1988). These sites are characterized by shallow soil with high pH and low water holding capacity, which developed in limestone residuum (Nigh et al. 1985). Two hypotheses concerning the development of *A. saccharum* on these sites have been advanced. Rochow (1972) suggested that *A. saccharum* trees on these sites were in fact a drought tolerant genotype that were able to colonize these poor sites. Nigh et al. (1985) suggested that either *A. saccharum* is more drought tolerant than previously thought or that on these sites it is able to develop a root system that penetrates cracks in the limestone bedrock, thereby acquiring access to water that accumulates in cavities between beds (Gates 1983).

---

[1] School of Natural Resources, University of Missouri-Columbia, Columbia, MO 65211.

The objective of this study was to examine the water relations and photosynthetic characteristics of two groups of *A. saccharum* trees—one group growing on a typical upland site, the other on a glade-like site—to determine whether *A. saccharum* on glade-like sites might be a drought-tolerant genotype or whether these trees have access to more abundant soil moisture than suggested by the xeric nature of the site.

MATERIALS AND METHODS

Study Area

The experiments were conducted at the Thomas H. Baskett Wildlife Area (BWA), formerly referred to as the Ashland Wildlife Area, located in southern Boone County, Missouri (38°N, 92°W). BWA is a 890-ha reserve owned and managed by the University of Missouri. The area is diverse in its cover types with old fields, plantations and second-growth hardwood forest (dominant canopy trees ranging from age 65 to 150 years) located in patches throughout the area. The area is underlain by limestone with the dominant soil types being: 1) Steep Stony Land, which is a broad classification for rocky slopes covered with a thin layer of soil and 2) Weller silt loam, which is an upland soil derived from loess parent material overlying glacial till (Pallardy et al., 1988).

The area selected for the experiments was chosen based on the presence of glade-like and upland sites in close proximity (< 200 meters) to one another. The second-growth forest occupying both sites has previously been described (Rochow 1972, Pallardy et al. 1988). The northern (Upland) site was a gentle East-facing slope in which the soil was relatively deep (> 1 m) with no bedrock outcroppings present. Dominant species on this site included *Q. alba* and *Q. velutina* and an understory dominated by *A. saccharum*. The Glade-like site was on a steep Southeast-facing slope possessing a shallow ($\leq$ 15 cm estimated depth) poorly-developed soil, and abundant limestone outcroppings. Dominant species on the Glade-like site included *A. saccharum*, chinkapin oak (*Quercus muehlenbergii* Engelm.) and eastern redcedar (*Juniperus virginiana* L.) with an understory that included species characteristic of prairies and xeric glades (e.g., sensitive brier [*Schrankia uncinata* Willd.], rose verbena [*Verbena canadensis* (L.) Britt.], puccoon [*Lithospermum canescens* (Michx.) Lehm., long-bracted wild indigo [*Baptisia leucophaea* Nutt.]).

Plant Material

Five *A. saccharum* trees were selected at each site. All were in the understory and less than 15 cm dbh. Trees were selected based on the following criteria:

1) availability of a large number of leaves and twigs within reaching distance,
2) healthy and vigorous appearance,
3) similarity in exposure (which was not more than 50 percent coverage by the canopy),

The same five upland and four of five glade-like site trees were sampled throughout the study. One glade-like site tree suffered severe insect damage in August and a different tree was selected for the final two sampling days.

Sampling Procedures

Pre-dawn leaf water potential (Ψ_{pd}), diurnal leaf water potential (Ψ_l) and diurnal net photosynthetic rate (P_{net}) were measured on five dates in 1990: June 11 and 12 (days 162 and 163); August 30 and September 4 (days 242 and 247) and September 20 (day 263). Days 162 and 163 followed a week in which 11.7 cm of rain fell at nearby Columbia Regional Airport (11 km distant). Days 242 and 247 were associated with a period of summer drought during which only 1.5 cm of rain fell in an 18 day period and day 263 was selected following two days in which about 1.5 cm of rain fell, partially recharging the surface soil.

Pre-dawn and Diurnal Physiological Measurements

One twig from each of five Upland and five Glade-like site trees was collected prior to sunrise. Twigs were sealed in a plastic bag with a moist paper towel. After all ten samples were collected, Ψ_{pd} was measured with a pressure chamber, using a pressurization rate of 0.005 $MPa \cdot s^{-1}$ (Ritchie and Hinckley 1975). Water potential was measured on twigs because *A. saccharum* leaves bubble profusely from the petiole, preventing accurate endpoint determination (Bahari et al. 1985).

Net photosynthesis was measured on two leaves per tree for each of the five control and each of the five exposed trees for a total of 20 measurements for each time period. Measurements were taken at four times: 0700-0800, 1000-1200, 1400-1500 and 1700-1800 hours. Net photosynthesis was measured with a LI-6200 Portable Photosynthesis System fitted with a 1 L leaf chamber (Li-Cor Inc., Lincoln, NE, USA). Photosynthetic Photon Flux Density (PPFD in $\mu mol \cdot m^{-2} \cdot s^{-1}$) was measured during measurement of P_{net} by a quantum sensor attached to the leaf chamber. Leaf temperature (T_l) was measured by a thermistor appressed to the lower leaf surface during P_{net} measurement and vapor pressure difference between leaf and air (VPD) was calculated from this variable and relative humidity of the air as measured in the cuvette. The analyzer was calibrated twice daily using bottled gas of a known CO_2 concentration.

Immediately following measurement of P_{net}, a twig was clipped from the sample tree and sealed in a plastic bag with a damp paper towel. Leaf Ψ was measured with a pressure chamber as described previously.

Data Analysis

The experiment was analyzed by repeated measures analysis of variance (PROC GLM, SAS Institute, Inc. 1982) with plants and times considered as repeated measures. Unless otherwise noted, least square means were calculated and mean comparisons performed if the treatment F-test was significant ($p \leq 0.05$). Multiple regression analysis of environmental variables and site on P_{net} also was conducted to examine the possibility of genetic differences in responses of trees on the two sites to environmental factors.

RESULTS

Pre-dawn Leaf Water Potential

Seasonal changes in Ψ_{pd} were evident in *A. saccharum* trees from both sites (Table 1). Analysis of variance of Ψ_{pd} indicated that there was a significant influence of sample day (i.e., representing variation in soil moisture), but no effect of treatment (Upland versus Glade-like site) nor was there an interaction effect of soil moisture and site (Table 1). Pre-dawn Ψ was significantly greater for trees sampled during periods when soil was moistened by recent rains.

Table 1.—Mean values of predawn and diurnal leaf water potential (Ψ_{pd}, Ψ_l) and diurnal net photosynthetic rate (P_{net}) of *Acer saccharum* trees growing on Upland (U) and Glade-like (G) sites. Within a column mean values not superscripted with the same letter are significantly different ($p \leq 0.05$). There were no significant differences between sites for either Ψ_{pd} or diurnal Ψ_l on any sample day.

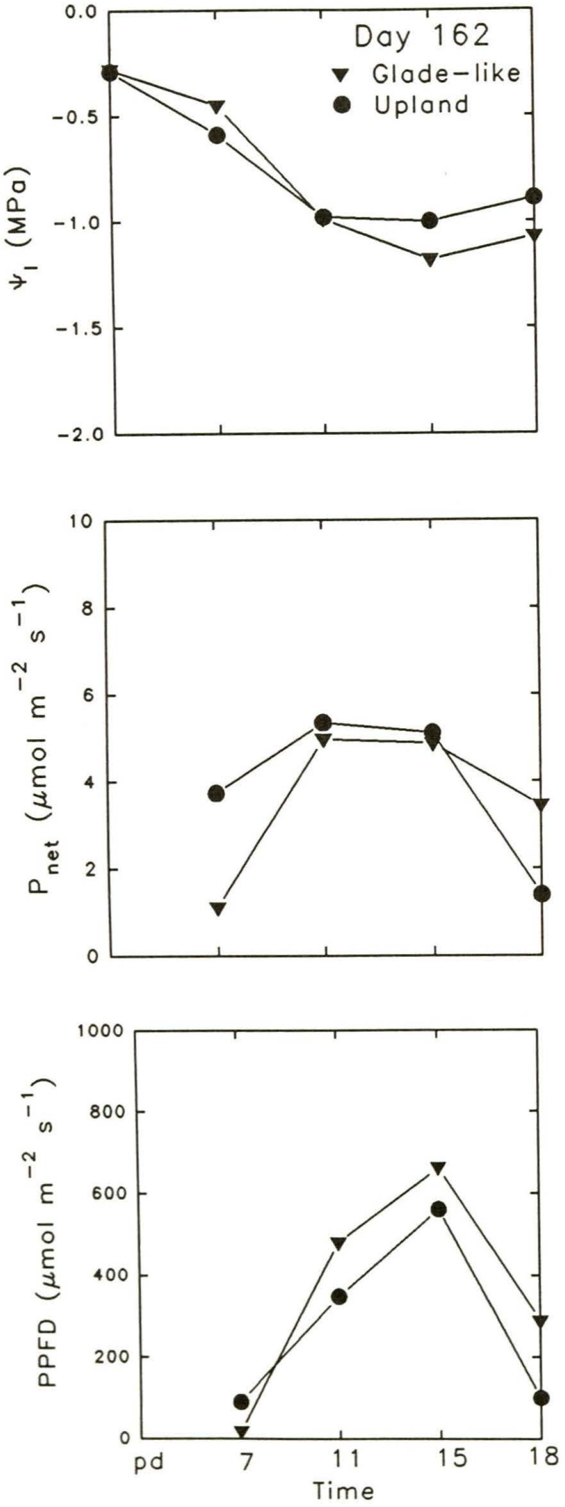
	Ψ_{pd} (MPa)		Ψ_l (MPa)		P_{net} (μmol m^{-2} s^{-1})	
Day	**U**	**G**	**U**	**G**	**U**	**G**
162	-0.29^{a}	-0.28^{a}	-0.86^{a}	-0.93^{ab}	3.89^{a}	3.60^{a}
163	-0.21^{a}	-0.27^{a}	-0.95^{ab}	-0.81^{a}	3.88^{a}	3.08^{a}
242	-0.72^{b}	-0.60^{b}	-1.34^{cd}	-1.27^{c}	3.54^{a}	3.48^{a}
247	-1.13^{c}	-1.16^{c}	-1.47^{d}	-1.35^{cd}	1.86^{b}	3.22^{a}
263	-0.41^{b}	-0.50^{b}	-0.83^{a}	-1.07^{b}	1.97^{b}	1.28^{b}

Diurnal Leaf Water Potential

The diurnal pattern of leaf water potential was similar for both control and exposed trees for all five sampling days (Figures 1, 2). Leaf Ψ for both Upland and Glade-like site trees was generally lowest in mid-afternoon, and in all but one case (Glade-like site trees on day 247) Ψ_l had recovered at least partially by late afternoon. Analysis of variance indicated that mean diurnal Ψ_l responded to soil moisture ($p \leq 0.05$), but there was no effect of site. Diurnal Ψ_l tended to decline and rise in concert with Ψ_{pd}.

Net Photosynthetic Rate

Net photosynthetic rate followed light intensity for both Upland and Glade-like site trees under both moist and dry soil conditions (Figures 1, 2). Net photosynthetic rate increased with PPFD except in cases where mean light intensity exceeded 500 $\mu mol \cdot m^{-2} \cdot s^{-1}$, in which case P_{net} declined (e.g., Figure 1). Diurnal patterns of PPFD and P_{net} were generally consistent for all five sampling days and for trees on both sites. Peak P_{net} generally occurred in the early or mid-afternoon; subsequent declines in P_{net} preceded the recovery of Ψ_l. There was no significant effect of site on P_{net} and no systematic relationship between soil moisture (represented by Ψ_{pd} and, indirectly, Ψ_l) and P_{net} over the course of the study (Tables 1, 2). Although late-season declines in P_{net} were observed, they had no discernible relationship to soil moisture patterns; rather, they were more closely related to diurnal PPFD ($p \leq 0.05$). While results of multiple regression analysis of P_{net} versus site and PPFD, Ψ_l, T_l and VPD (Table 2) revealed relationships between environmental variables and P_{net}, there were no differences in response of P_{net} to environmental variables between sites. The apparent site difference in response of P_{net} to PPFD was actually related to variation in mean PPFD levels between Upland and Glade-like sites (mean PPFD on these sites was 296 and 149 $\mu mol\ m^{-2}\ s^{-1}$, respectively).



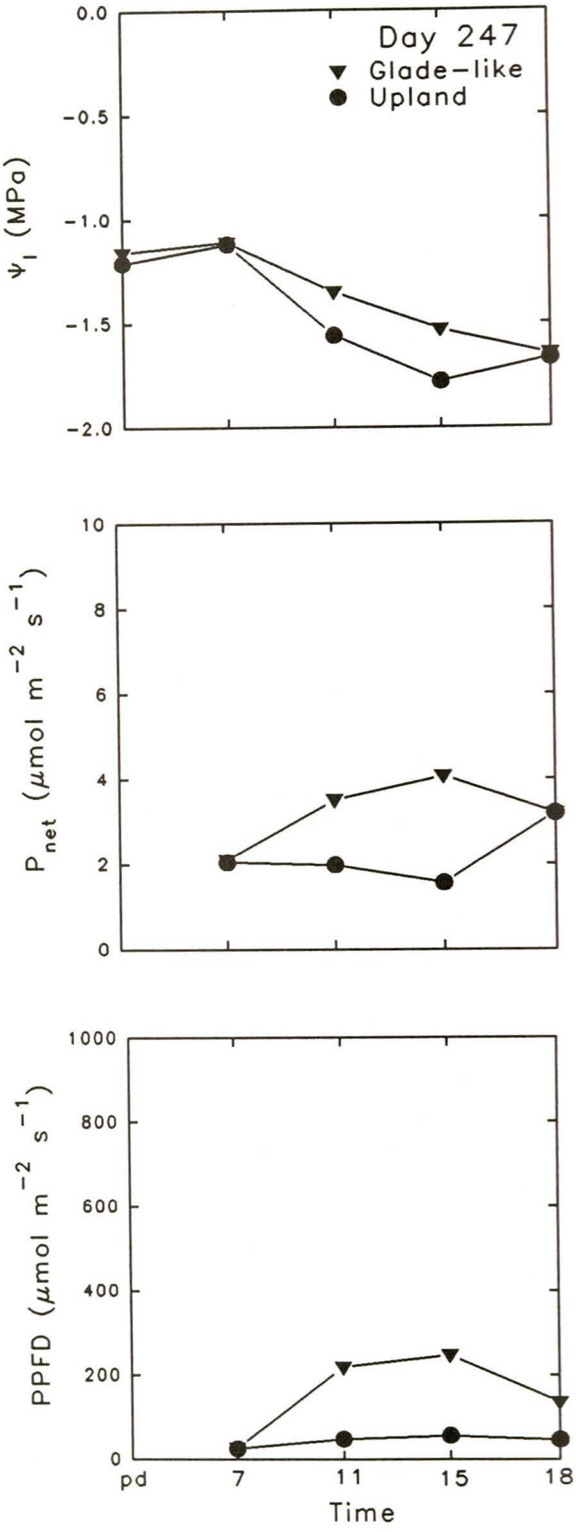


Figure 1. (Left).—Diurnal cycle of mean light intensity (PPFD), net photosynthetic rate (P_{net}) and leaf water potential (Ψ_l) of Upland (•) and Glade-like (∇) site trees for a sample day representing moist soil conditions (Day 162).

Figure 2. (Right).—Diurnal cycle of light intensity (PPFD), net photosynthetic rate (P_{net}) and leaf water potential (Ψ_l) of Upland (•) and Glade-like (∇) site trees for a sample day representing dry soil conditions (Day 247).

Table 2.—Results of multiple regression analysis of net photosynthetic rate as a function of site and environmental variables (diurnal leaf water potential [Ψ_l], photosynthetic photon flux density [PPFD] leaf temperature, [T_l]) and vapor pressure difference between leaf and air [VPD]).

Independent variable	**Source** **Variable**	**Site**	**Variable x Site**
Ψ_l	ns[a]	ns	ns
PPFD	**	ns	**
T_l	**	ns	ns
VPD	**	ns	ns

[a] ns = not significant ($p > 0.05$); ** = significant ($p \leq 0.01$)

DISCUSSION

Analysis of Ψ_{pd} showed that trees on both sites experienced a period of drought late in the summer, despite precipitation that was above normal for the entire growing season. Pre-dawn leaf water potential approximates the equilibrium water potential reached between the plant and the soil as transpiration is negligible at this time (Ritchie and Hinckley 1975). No differences in Ψ_{pd} were observed between Upland and Glade-like site trees under moist or dry soil moisture conditions. It can be inferred, then, that *A. saccharum* on both sites had approximately equal access to a water supply, both during drought and in moist soil.

There were no indications, at least at the level of the phenotype, that the *A. saccharum* population growing on the Glade-like site were more drought tolerant. Bunce et al. (1977) suggested that species which were more dehydration tolerant would be better able to sustain gas exchange under drought than species which were less dehydration-tolerant. This line of reasoning would suggest that a dehydration-tolerant genotype of *A. saccharum* should show greater P_{net} during drought conditions. Analysis of the responses of P_{net} to environmental variables indicated no phenotypic differences between trees growing on the two sites in physiological responses to leaf water stress, nor to light intensity or leaf temperature. It must be noted that the drought developed during 1990 was not as severe as in certain other years (e.g., Hinckley et al. 1979, Bahari et al. 1985). This was reflected in the lack of a relationship between leaf water status and gas exchange (Table 2). It is possible that during an extreme drought year site differences might have been evident, but the evidence presented here offers no support for such a possibility.

These facts, coupled with the lack of significant differences between Upland and Glade-like site trees in Ψ_{pd} and Ψ_l as outlined previously, argues against the existence of a dehydration-tolerant genotype of *A. saccharum*, as was suggested by Rochow (1972). Nigh et al. (1985) further reported that there were no obvious morphological distinctions between *A. saccharum* inhabiting the glade-like limestone outcroppings and those growing on more mesic sites. These authors suggested that *A. saccharum* might have access to deep sources of water through root growth into the cracks between limestone beds. Excavation of dolomitic limestone beds by Gates (1983) revealed large cavities between the beds which could serve as reservoirs of water. The evidence presented here is consistent with this proposed mechanism.

LITERATURE CITED

Bahari, Z.A., S.G. Pallardy and W.C. Parker. 1985. Photosynthesis, water relations, and drought adaptation in six woody species of oak-hickory forests in central Missouri. For. Sci. 31: 557-569.

Bunce, J.A., L.N. Miller and B.F. Chabot. 1977. Competitive exploitation of soil water by five eastern North American tree species. Bot. Gaz. 138: 168-173.

Gates, J. 1983. The hydrology of a glade in southwest Missouri. M.S. Thesis, University of Missouri, Columbia. 164 p.

Hett, J.M. and O.L. Loucks. 1971. Sugar maple (*Acer saccharum* Marsh.) seedling mortality. J. Ecol. 59: 507-520.

Hinckley, T.M., et al. 1978. Leaf conductance and photosynthesis in four species of the oak-hickory forest type. For. Sci. 24: 73-84.

Hinckley, T.M., et al. 1979. A severe drought: impact on tree growth, phenology, net photosynthetic rate and water relations. Am. Midl. Nat. 102: 307-316.

Nigh, T.A., S.G. Pallardy and H.E. Garrett. 1985. Sugar maple-environment relationships in the River Hills and central Ozark Mountains of Missouri. Am. Midl. Nat. 114: 235-251.

Pallardy, S.G., T.A. Nigh and H.E. Garrett. 1988. Changes in forest composition in central Missouri: 1968-1982. Am. Midl. Nat. 120: 380-389.

Ritchie, G.A. and T.M. Hinckley. 1975. The pressure chamber as an instrument for ecological research. pp. 165-254. In Advances in Ecological Research, (A. Macfayden, ed.), Vol. 9. Academic Press, New York.

Rochow, J.J. 1972. A vegetational description of a mid-Missouri forest using gradient analysis techniques. Am. Midl. Nat. 87: 377-396.

SAS Institute, INc. 1982. User's guide to the Statistical Analysis System: Statistics. SAS Institute, Cary, North Carolina.

Weber, J.A., et al. 1985. Analysis of gas exchange in seedlings of *Acer saccharum*: integration of field and laboratory studies. Oecologia 65: 338-347.

The Endangered Karner Blue Butterfly (Lepidoptera: Lycaenidae): Biology, Management Considerations, and Data Gaps

Robert A. Haack[1]

Abstract: The Karner blue butterfly, *Lycaeides melissa samuelis* Nabokov, became federally listed as endangered in 1992 and is thus afforded protection under the Endangered Species Act of 1973. This insect has a very discontinuous range, with 1992 populations found in Minnesota, Wisconsin, Illinois, Indiana, Michigan, New York, and New Hampshire. Karner blue larvae feed exclusively on wild lupine, *Lupinus perennis* L., a disturbance-adapted plant common to oak savannas, pine barrens, and lake dune complexes. Historically, Karner blue sites have been maintained by fire. Besides lupine, the Karner blue requires nectar sources for adults and possibly ants for protection of the larvae. This paper provides current information on Karner blue distribution, taxonomy, general biology, habitat requirements, management practices, and data gaps.

INTRODUCTION

The Karner blue butterfly, *Lycaeides melissa samuelis* Nabokov (Lepidoptera: Lycaenidae), occurs primarily in oak savannas and pine barrens, and occasionally in lake dune complexes from Minnesota to New Hampshire. Over the past 100 years it is estimated that the Karner blue has declined by 99% in numbers (USFWS 1992). In December 1992 the Karner blue was federally listed as endangered (USFWS 1992), and therefore now receives protection under the Endangered Species Act of 1973 (Pyle et al. 1981, Rohlf 1989, Wilcove et al. 1993). Land managers with known Karner blue populations should follow management prescriptions to ensure its survival and recovery as stipulated in the Endangered Species Act. To assist managers, this paper summarizes much of what is known about Karner blue biology, habitat requirements, and management considerations.

DISTRIBUTION

The Karner blue is found in small pockets from Minnesota to New Hampshire, generally following the northern limits of the range of wild lupine, *Lupinus perennis* L., the insect's only larval food plant (Figure 1). Originally the Karner blue probably existed as several, large shifting clusters of populations, or metapopulations, waxing and waning as lupine first entered recently burned areas and then left when successional changes shaded out the plant (USFWS 1992, Schweitzer 1990). As of 1992, the Karner blue existed in Minnesota, Wisconsin, Illinois, Indiana, Michigan, New York, and New Hampshire (Table 1), with Michigan and Wisconsin appearing to have the most (but not the largest) discrete populations (USFWS 1992). In addition, this butterfly once existed in Massachusetts, Ohio, Pennsylvania, and Ontario (Figure 1, Table 1). In Illinois, 5 adults (3 males and 2 females) were reported in 1992, being the first confirmed occurrence of Karner blue in Illinois since about 1900 (S. Lauzon, pers. comm., Downey 1966). Because of some early confusion regarding these sightings in Illinois, 7 adults instead of 5 were reported in USFWS (1992).

---

[1] Research Entomologist, North Central Forest Experiment Station, USDA Forest Service, Insect Project, 1407 S. Harrison Rd., East Lansing, MI 48823.

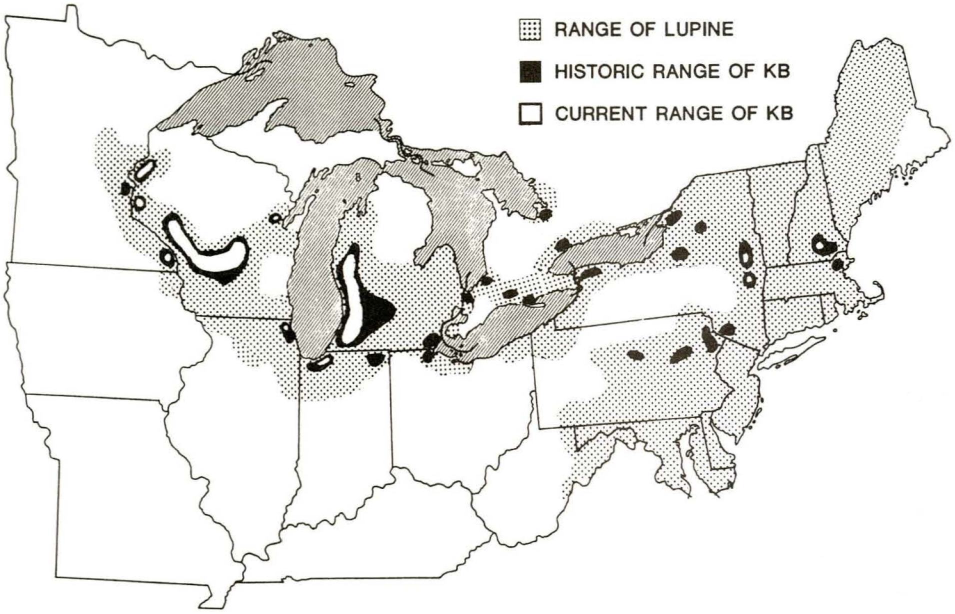


Figure 1.—Approximate range maps of wild lupine (incomplete, not showing extension southward to Florida), and the historic and current (1992) ranges of Karner blue (KB). The northern range of lupine was estimated from county records taken from over 30 books on the flora of individual states and regions (list of references available from the author), and from lupine survey records of the Wisconsin Department of Natural Resources. Karner blue sources include: Cryan and Dirig (1978); briefing material presented at the "Karner Blue Butterfly Population and Habitat Viability Assessment (PHVA) Workshop," April 22-24, 1992, Zanesville, OH; and comments from several reviewers (see acknowledgments).

ENDANGERED STATUS

Because of its dramatic rangewide decline, the Karner blue was proposed on January 21, 1992, for federal listing as "endangered" under the Endangered Species Act; this proposal became final on December 14, 1992 (USFWS 1992). The designation "endangered" signifies a species in danger of extinction throughout all or a significant part of its range (Haack 1992, Rohlf 1989, Wilcove et al. 1993). Having been afforded endangered species status, the Karner blue is protected from actions that could jeopardize either the insect itself or its "critical habitat." For example, gypsy moth control programs, using the lepidopteran-specific *Bacillus thuringiensis* (*Bt*) insecticide, could be banned from areas with known Karner blue populations because of the possible "non-target" effects of *Bt*. Although it is not yet known if Karner blue is sensitive to *Bt*, a "no-spray" policy would likely be taken as a precautionary step.

TAXONOMY

The Karner blue was originally described in 1861 under the name *Lycaeides scudderi* Edwards, being considered then the same species as the Scudder's blue. However, after a revision by Nabokov (1943) it was reclassified as a subspecies of the Melissa blue (*Lycaeides melissa melissa* Edwards), with the scientific name of *Lycaeides melissa samuelis* Nabokov. Although there is evidence that the Karner blue deserves full species status, no such change has yet been published (Schweitzer 1989, USFWS 1992). The type specimen of the Karner blue was collected near Karner, New York, from which its common name was derived.

Table 1.—Status of the Karner blue throughout its current and historical rangeas of 1992

Location	**Current status (Current and recent references)***
Minnesota	5 sites in 1 population cluster; ≤14 adults/site seen in 1991 (8 13 20)
Wisconsin	131 sites in 1991; ≤100 adults seen at 90% of sites (4, 20)
Illinois	Considered extirpated ca. 1900; 5 adults reported in 1992 (20, 22)
Indiana	10 discrete sites in 2 population clusters in 2 counties (20, 24)
Michigan	Minimum of 93 sites in 6 counties (1, 2, 9, 14, 20, 21, 23)
Ohio	Extirpated since 1988 (10, 15, 19, 20)
Pennsylvania	Extirpated since about 1900 (16, 20)
New York	About 50 small and 2 large (1500 and 14,000 adults) sites (6, 7, 18, 20)
New Hampshire	1 site on 2-3 acres; 400 adults estimated in 1991 (3, 11, 20)
Massachusetts	Extirpated possibly before 1900 (20)
Ontario	Extirpated since about 1989 (12, 17, 20)

*References: 1=Ballard and Sferra (1991), 2=Bess (1989), 3=Bidwell (1991), 4=Bleser (1992), Campbell et al. (1990). 6=Cryan (1980), 7=Cryan and Dirig (1978), 8=Cuthrell (1990), 9=Ewert and Ballard (1990), 10=Grigore (1992), 11=Helmboldt and Amaral (1992), 12=Konecny (1986), 13=Lane (1992), 14=Lawrence and Cook (1989), 15=Magdich (1989), 16=Opler (1985), 17=Packer (1990), 18=Schweitzer (1990), 19=Shuey et al. (1987), 20=USFWS (1992), 21=Wilsmann (1992), 22=S. Lauzon, personal communication, 23=M. Rabe personal communication, Michigan Natural Features Inventory, 24=M. Martin (1992).

DESCRIPTION

Karner blue adults are rather small butterflies with a wingspan between 2.2 and 3.2 cm (Opler and Krizek 1984, Scudder 1889, USFWS 1992). The dorsal or upper wing surface of males is purplish (or silvery) blue with a narrow black border and a white fringe. The dorsal wing surface of females is similar to that of males except there is more brown and the outer edge of the female's hind wings has a row of dark spots with orange crescents. The ventral or lower surface of the wings is similar in both males and females—slate gray with several rows of black and orange spots. High quality Karner blue photographs are given in Opler and Krizek (1984), Shull (1987), and several other butterfly guides.

Eggs are about 0.7 mm in diameter, pale green, and somewhat rounded (Dirig and Cryan 1976, Scudder 1889). The egg's surface is highly sculptured or reticulated, appearing as a raised network of fine lines.

Larvae are dorsally flattened and pubescent, with black head capsules and green bodies (Dirig and Cryan 1976, Scudder 1889). Older larvae have a dark-green median stripe along the upper surface of the abdomen and white stripes laterally. Karner blue larvae are well camouflaged for feeding on lupine leaves. There are four larval instars (Savignano 1990). Scudder (1889) reports that first instar larvae measure about 1.25 mm in length, while fourth instars measure 12.25 mm long. Pupae are smooth, pea-green, and about 9.5 mm long (Scudder 1889). Pupae turn blackish purple just prior to adult emergence (C. Bleser, pers. comm.).

Life Cycle

The Karner blue's life history is generally well documented, with the following details taken from Bleser (1992), Cryan (1980), Cryan and Dirig (1978), Dirig (1973, 1988), Lawrence and Cook (1989), Masters and Karpuleon (1975), Packer (1987, 1990), Savignano (1990), Shapiro (1974), Schweitzer (1989), Scudder (1888, 1889), and Shuey et al. (1987). It is a bivoltine insect, i.e., it completes two generations per year (Figure 2) with the egg being the overwintering stage. The exact timing of each life stage varies somewhat within the species' geographic range, and from year to year, depending on local weather conditions. First-generation larvae hatch from eggs in middle to late April, and immediately search out and feed on wild lupine, their sole host plant. While feeding, young larvae make pinprick-sized circular holes in leaves or they skeletonize the leaves, which results in a window-pane appearance. Older larvae feed primarily on foliage, but may feed on lupine buds, flowers, and developing fruit. Larvae feed for about 3 to 4 weeks. First-generation pupation occurs primarily in late May to early June and lasts for about 8-11 days. Pupae are usually found on lupine plants or in nearby litter. First-generation adults fly from late May through mid-June. Adults typically live for about 5 days, but may live as long as 2 weeks. Peak male flight typically precedes peak female flight by a few days, as is true in many Lepidoptera. First-generation adults lay eggs on lupine plants, often singly on leaves, petioles, or stems. The male:female ratio is about 1:1.

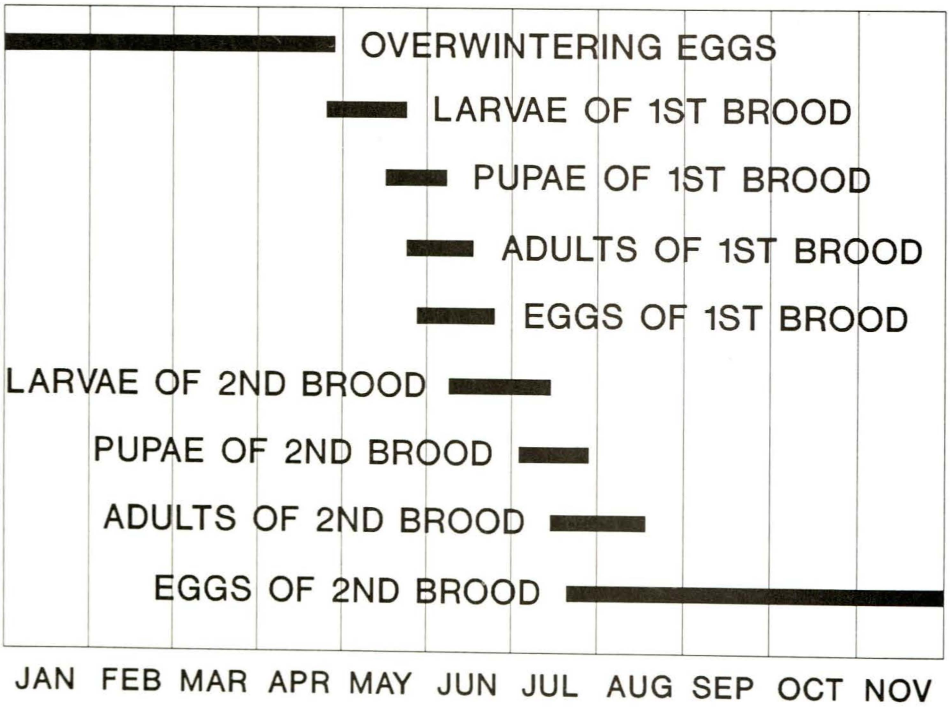


Figure 2.—Generalized occurrence of various Karner blue life stages through a typical year.

Larvae of the second generation can be found feeding on lupine from early June through late July. Second-generation adults typically fly from mid-July into early August. There are usually 3-4 times more individual adults in the second brood than in the first brood at a given locality. Second-generation adults lay eggs at or near the bases of lupine plants, on dry lupine pods, or low on the stems of surrounding vegetation. During the second-generation flight period, at which time lupine plants are senescing, adults do not appear to discriminate between dry and green plants for oviposition.

Adults initiate flight between 8-9 a.m. and continue to fly until about 7 p.m. Flight activity is greatly reduced below 75°F or during moderate to heavy rains. Adults tend to fly close to the ground. At night, they roost in open areas on grasses such as bluestem, *Schizachyrium* (=*Andropogon*). Adults can disperse at least as far as 1-1.5 km, which seemingly would help them search for new patches of lupine. However, in some populations (e.g., in New Hampshire), adults disperse very little (D. Schweitzer pers. comm.).

Nectar Sources

Karner blue adults obtain nectar from a wide variety of flowering plants, including both native and exotic species (Table 2). Lupine is used as a nectar source by first-generation adults, but few lupine plants are still flowering when second-generation adults fly. Although lupine is the sole larval host plant, it is not a favored nectar plant for adults (Leach 1993). Wide variation in the favored nectar plants occurs from state to state. However, New Jersey tea (*Ceanothus americanus*) is among the favorite nectar sources in Indiana, New Hampshire, New York, and Ontario (D. Schweitzer in press-b). A lack of nectaring plants, especially during the second-generation flight season, can render sites unsuitable for Karner blue even though lupine may abound (Bleser 1992, Leach 1993, Schweitzer 1989).

Association with Ants

Karner blue larvae, like many members of the family Lycaenidae, are associated with ants (Bleser 1992, Packer 1990, Savignano 1990, Scudder 1889). Reports from New York, Wisconsin, and Ontario have identified 27 species of ants that tend Karner blue caterpillars (Table 3). There is one report of ants tending a Karner blue pupa (Saunders 1878).

Lycaenid caterpillars and pupae have special glands that secrete juices high in sugars and amino acids that are harvested by ants (DeVries 1988, 1992, Maschwitz et al. 1975). In return for these nutritious secretions, ants protect lycaenid caterpillars and pupae from predation and parasitism (Atstatt 1981a, Jordano et al. 1992, Peterson 1993, Pierce and Easteal 1986). Savignano (1990) has reported lower predation of Karner blue larvae when tended by ants. Many lycaenid caterpillars, and perhaps Karner blue larvae as well, produce sounds that ants use to locate the larvae (Bleser 1992, DeVries 1988, 1989, 1992).

In addition, some lycaenids oviposit preferentially in habitats with ants (Atstatt 1981b, Pierce and Elgar 1985), which may help explain why lycaenid larvae are often found in close spatial proximity to ants (Jordano et al. 1992, Smiley et al. 1988). If these relationships hold true for the Karner blue, then it may be discovered that adults seek out and oviposit in habitats with both lupine and selected ant species. Packer (1987) suggested that a drastic decline in wood ant populations contributed to local declines of Karner blue in Ontario.

Table 2.—Nectaring sources for first-generation and second-generation Karner blue adults

Plant			
Scientific name	**Common name**	**Location**	**Reference**
First generation nectaring sources			
Achillea millefolium	Yarrow	WI	2 13
Amelanchier sp.	Juneberry	NY ONT	3 7
Anemone cylindrica	Thimbleweed	WI	13
Arabis lyrata	Lyre-leaved rock cress	IN ONT WI	2 7 12 13
Arenaria serpyllifolia	Thyme-leaved sandwort	ONT	7
Baptisia leucophaea	Wild indigo	WI	2
Berteroa incana	Hoary alyssum	WI	2 13
Ceanothus ovatus	Red root	WI	13
Ceanothus sp.	New Jersey tea	WI	2
Centaurea maculosa	Spotted knapweed	WI	13
Cerastium sp.	Chickweed	WI	13
Chrysanthemum leucanthemum	Daisy	WI	13
Comandra umbellata	Bastard toadflax	MI WI	2 10
Coreopsis lanceolata	Lance-leafed coreopsis	IN	12
Erigeron strigosus	Daisy fleabane	WI	13
Euphorbia esula	Leafy spurge	WI	13
Fragaria virginiana	Strawberry	NY WI	9 13
Gaylussacia baccata	Huckleberry	WI	2
Geranium maculatum	Wild geranium	ONT	7
Helianthemum canadense	Frostweed	NH	1 5
Hieracium aurantiacum	Orange hawkweed	WI	2 13
Hieracium sp.	Hawkweed	NH NY ONT	5 7 9
Houstonia longifolia	Long-leaved bluets	WI	2
Krigia biflora	Two-flowered cynthia	WI	2
Lithospermum caroliniense	Hairy puccoon	ONT WI	2 7
Lupinus perennis	Wild lupine	MI NH ONT WI	1 2 4 5 7 13
Medicago lupulina	Black medick	WI	2 13
Melilotus officinalis	Yellow sweet clover	IN WI	2 12 13
Pedicularis canadensis	Lousewort	WI	2
Phlox pilosa	Downy phlox	IN	12
Physocarpus opulifolius	Nine-bark	WI	13
Potentilla recta	Rough-fruited cinquefoil	WI	2
Potentilla simplex	Common cinquefoil	MI NY WI	2 8 10 13
Prunus sp.	Wild plum	NY	3 8
Rubus allegheniensis	Blackberry	MI	4 10
Rubus flagellaris	Dewberry	IN	12
Rubus sp.	Blackberry	IN NY WI	3 9 12 13
Rubus sp.	Dewberry	WI	13
Rumex acetosella	Sheep sorrel	WI	2
Salix humilis	Prairie willow	WI	2 13
Senecio pauperculus	Ragwort	WI	13
Senecio sp.	Ragwort	WI	2
Smilacina racemosa	False Solomon's seal	WI	2 13
Smilacina stellata	Starry false Solomon's seal	WI	2
Trifolium pratense	Red clover	WI	13
Trifolium repens	White clover	WI	13
Trifolium hybridum	Alsike clover	WI	2
Vaccinium sp.	Blueberry	NY	3 9
Vicia villosa	Vetch	WI	2
Viola pedata	Bird's-foot violet	WI	2
Zizia aurea	Golden alexanders	WI	2

Table 2. (Continued)

Plant			
Scientific name	**Common name**	**Location**	**Reference**
Second generation nectaring sources			
Achillea millefolium	Yarrow	IN WI	2 12 13
Amorpha canescens	Leadplant	NY WI	2 9 13
Apocynum androsaemifolium	Spreading dogbane	NH	1
Arabis lyrata	Lyre-leaved rock cress	IN WI	2 12 13
Asclepias syriaca	Common milkweed	WI	2 13
Asclepias tuberosa	Butterfly weed	IN MI ONT WI	2 4 7 12 13
Asclepias verticillata	Whorled milkweed	IN WI	2 12 13
Aster ptarmicoides	Upland white aster	WI	2
Aureolaria pedicularia	False foxglove	WI	2
Berteroa incana	Hoary alyssum	WI	2
Campanula rotundifolia	Bluebell	MN	6
Ceanothus americanus	New Jersey tea	IN NH NY ONT	1 5 7 9 12
Ceanothus herbaceus	New Jersey tea	ONT	7
Centaurea maculosa	Spotted knapweed	MI NY WI	2 4 9 10 13
Chrysanthemum leucanthemum	Daisy	WI	13
Coreopsis palmata	Coreopsis	WI	13
Coreopsis sp.	Coreopsis	WI	2
Erigeron sp.	Daisy fleabane	IN	12
Erigeron annuus	Daisy fleabane	MI	10
Erigeron strigosus	Daisy fleabane	MI WI	2 10 13
Euphorbia corollata	Flowering spurge	IN MI WI	2 4 10 12 13
Euphorbia esula	Leafy spurge	WI	2 13
Froelichia floridana	Cottonweed	WI	13
Galium sp.	Bedstraw	WI	2
Gerardia pedicularia	Fern-leaved false foxglove	WI	2
Gnaphalium obtusifolium	Sweet everlasting	MN	6
Helianthus divaricatus	Woodland sunflower	IN	12
Helianthus occidentalis	Western sunflower	WI	2 13
Hieracium aurantiacum	Orange hawkweed	WI	2 13
Houstonia longifolia	Long-leaved bluets	WI	2
Krigia biflora	Two-flowered cynthia	WI	2
Lespedeza capitata	Round-headed bush-clover	WI	2
Liatris aspera	Rough blazing-star	MI WI	4 13
Liatris cylindracea	Cylindric blazing-star	WI	2 13
Lilium philadelphicum	Wood lily	NH	1 5
Linaria vulgaris	Butter-and-eggs	WI	2
Lithospermum caroliniana	Hairy puccoon	WI	2
Lobelia spicata	Pale-spike lobelia	WI	13
Lotus corniculatus	Birdfoot trefoil	WI	2
Lupinus perennis	Wild lupine	WI	2
Lysimachia sp.	Loosestrife	WI	2
Medicago lupulina	Black medick	WI	13
Medicago sativa	Alfalfa	WI	2
Melilotus alba	White sweet clover	IN MI NY WI	9 11 12 13
Melilotus officinalis	Yellow sweet clover	WI	2 13
Monarda fistulosa	Wild bergamot	IN ONT	7 12
Monarda punctata	Horsemint	IN MI MN NY WI	2 3 4 6 12 13
Oenothera sp.	Evening primrose	WI	2
Petalostemum candidum	White prairie-clover	WI	2 13
Petalostemum purpureum	Purple prairie-clover	WI	2 13
Phlox pilosa	Downy phlox	IN	12

Table 2. (Continued)

Plant			
Scientific name	**Common name**	**Location**	**Reference**
Potentilla simplex	Old-field cinquefoil	WI	2
Polygala polygama	Racemed milkwort	WI	2
Polygonum sp.	Smartweed	WI	2
Rosa sp.	Rose	WI	2
Rudbeckia hirta	Black-eyed Susan	ONT WI	2 7 13
Saponaria officinalis	Bouncing bet	NY	8
Smilacina stellata	Starry false Solomon's seal	WI	2
Solidago graminifolia	Lance-leaved goldenrod	WI	2
Solidago speciosa	Showy goldenrod	WI	2
Solidago sp.	Goldenrod	IN NH	1 5 12
Spiraea alba	Narrowleaf meadowsweet	WI	2
Spiraea tomentosa	Steeplebush	WI	2
Talinum rugospermum	Fameflower	WI	2 13
Tephrosia virginiana	Goat's-rue	IN	12
Trifolium arvense	Rabbit's-foot clover	WI	2
Trifolium hybridum	Alsike clover	WI	2
Trifolium pratense	Red clover	WI	2 13
Trifolium repens	White clover	WI	2 13
Vicia villosa	Vetch	WI	2
Tephrosia virginiana	Goat's-rue	NY WI	2 3

*References: 1=Bidwell (1991), 2=Bleser (1990, 1992), 3=Cryan (1980), 4=Ewert and Ballard (1990), 5=Helmboldt and Amaral (1992), 6=Lane (1992), 7=Packer (1990), 8=Savignano (1987), 9=Schweitzer (1989), 10=Sferra and Darnell (1992), 11=Wilsmann (1992), 12=Martin (1992), 13=Leach (1993), 14=D. Schweitzer personal communication.

Predators and Parasites

Only a few Karner blue predators and parasites have been reported. Larval predators include spiders (Packer 1987), pentatomid stink bugs, *Polistes* wasps, and *Formica* ants (Savignano 1990). Similarly, adult predators include crab spiders, robber flies, ambush bugs, assassin bugs, and dragonflies (Bleser 1992, M. Leach pers. comm., Packer 1987, Savignano 1990 and unpub. data). Savignano (1990) reported four larval parasites of the Karner blue — the tachinid fly *Aplomya theclarum*, the braconid wasp *Apanteles* sp. (possibly *epinotiae*), and two ichneumonid wasps, *Neotypus nobilitator nobilitator* and *Parania geniculata*. Savignano (1990) reared the tachinid *Aplomya theclarum* from both first- and second-generation Karner blue larvae, suggesting that it may be a lycaenid specialist. In Stone et al. (1983), however, no host data are reported for this fly. Of the three parasitic wasps, Krombein et al. (1979) list several lepidopteran hosts (although none are lycaenids) for *A. epinotiae* and *P. geniculata*, whereas only one host is given for *N. nobilitator nobilitator*—the eastern tailed blue, *Everes comyntas* (Lycaenidae).

General Habitat

The Karner blue is primarily found in openings within habitats classified as oak savannas, pine-oak savannas, or pine barrens (Shuey in press). Such habitats have declined dramatically in acreage throughout North America. For example, Nuzzo (1986) estimates that only 0.02% of the presettlement acreage of oak savannas in the Midwest still existed as of 1985. In addition to savanna-type habitats, the Karner blue occasionally occurs in dry sand prairies and some lake shore dune complexes where lupine exists (Bess 1989, Martin 1992). Generally, the Karner blue is associated with areas of low canopy cover (<5% in Minnesota; Lane 1992), but at times this butterfly occurs under semi-closed canopy conditions as well (Leach 1993).

Table 3.—Ant species reported to tend Karner blue larvae

Ant species	Location	Reference
Aphaenogaster rudis	Ontario	Packer (1990)
Camponotus americanus	NY	Savignano (1990)
Camponotus ferrugineus	WI	Bleser (1992)
Camponotus novoboracensis	NY	Savignano (1990)
Camponotus pennsylvanicus	Ontario	Packer (1990)
Crematogaster ashmeadi	WI	Bleser (1992)
Crematogaster cerasi	NY	Savignano (1990)
Dolichonderus plagiatus	NY	Savignano (1990)
Formica exsectoides	Ontario	Packer (1990)
Formica fusca	WI	Bleser (1992)
Formica (Neoformica) incerta	NY	Savignano (1990)
Formica lasioides	NY	Savignano (1990)
Formica (Neoformica) nitidventris	NY	Savignano (1990)
Formica (Neoformica) schaufussi	NY	Savignano (1990)
Formica lasioides	NY	Savignano (1990)
Formica montana	WI	Bleser (1992)
Formica schaufussi	WI	Bleser (1992)
Formica subsericea	NY	Savignano (1990)
Lasius alienus	NY	Savignano (1990)
Lasius neoniger	NY	Savignano (1990)
Monomorium emarginatum	NY	Savignano (1990)
Myrmica americana	NY	Savignano (1990)
Myrmica punctiventris	Ontario	Packer (1990)
Myrmica sculptilis	NY	Savignano (1990)
Paratrechina parvula	NY	Savignano (1990)
Tapinoma sessile	NY, WI	Bleser (1992), Savignano (1990)
Tetramorium caespitum	WI	Bleser (1992)

Pitch pine, *Pinus rigida*, is the dominant pine species in the pine barrens of the eastern part of the Karner blue's range, while jack pine, *Pinus banksiana*, is the most common pine at the western end (i.e., in the Lake States). Similarly, scrub oak, *Quercus ilicifolia*, and dwarf chestnut oak, *Quercus prinoides*, prevail in the east, while northern pin oak, *Quercus ellipsoidalis*, white oak, *Quercus alba*, and black oak, *Quercus velutina*, are the common oaks in the western range of the Karner blue (Bess 1989, Cryan 1980, Cryan and Dirig 1978, Lane 1992, Masters and Karpuleon 1975, Savignano 1990). These habitats are typically dry and sandy, and historically have been maintained by fire (Nuzzo 1986, Shuey in press). Because lupine generally expands after a disturbance opens the canopy and the soil, fire or other disturbances are believed to be important in maintaining lupine in the landscape. Similarly, lupine and Karner blue are often found in disturbed areas such as along gas and powerline rights-of-way, sand pits, highway margins, edges of trails and dirt roads, and abandoned farm fields.

Lupine

The exclusive larval food plant of the Karner blue is wild lupine, a sun-loving, long-lived perennial legume, with a deep taproot (Boyonoski 1992, Grigore 1992). Lupine fixes nitrogen by means of the obligate bacterial symbiont *Rhizobium lupini*. The range of lupine extends from Minnesota to

Maine, through southern Ontario, and south along the Atlantic seaboard to the Gulf coast (Figure 1). In the northern portion of its range, lupine typically begins to grow in late March or early April, flowers during May and June, sets seed by mid-July, and senesces during late July and August (Dirig 1973, Grigore 1992). Lupine grows well in full sunlight as well as partial shade, but does not survive for very long in complete shade (Bess 1989, Smallidge and Leopold, in prep.). Leach (1993) reports that lupine appears to do best in areas with a mosaic of both sun and shade. Lupine is becoming rare in many parts of its range, reflecting in large part the decades of effective fire suppression and subsequent canopy closure (Shuey in press). Although fire is important in maintaining habitats suitable for lupine growth, fire can cause high mortality to lupine seed and seedlings (Boyonoski 1992, Grigore 1992).

Other Lupine Feeders

In addition to the Karner blue, there are two other local (and rare) lupine-feeding Lepidoptera: the frosted elfin, *Incisalia irus* (Lycaenidae), and the Persius dusky wing, *Erynnis persius* (Hesperiidae) (Shapiro 1974, Shuey et al. 1987). Ideally, the management practices selected to favor lupine and Karner blue should also benefit these other two lepidopterans (Campbell et al. 1990, Packer 1990, Schweitzer in press-a). Moreover, barrens and savanna communities are home to many other rare plants, invertebrates, and vertebrates, and probably all would be helped by efforts to restore and maintain these habitats. For example, Michigan Karner blue sites harbor many state-listed rare plants such as western silvery aster (*Aster sericeus*), side-oat grama (*Bouteloua curtipendula*), yellow flax (*Linum sulcatum*), Allegheny plum (*Prunus alleghaniensis*), and prairie smoke (*Geum triflorum*); rare invertebrates such as the dusted skipper (*Atrytonopsis hianna*, Persius dusky wing, Ottoe's skipper (*Hesperia ottoe*), frosted elfin, and regal fritillary (*Speyeria idalia*); and rare vertebrates like the eastern box turtle (*Terrapene carolina carolina*).

Minimum Habitat Requirements

Overall, the Karner blue appears to have two undisputed requirements: lupine for larvae and nectar sources for adults. Two other factors that may prove equally important are ants for protection of larvae and some source of shade (Leach 1993, Packer 1990). If any of these factors is lacking, the Karner blue could decline or perish at a given site.

A discussion about the acreage required to support Karner blue can be focused at the level of remnant demes as well as at the metapopulation level; see Schweitzer (in press-a,b) for a detailed discussion. Openings that support Karner blue do not need to be extremely large. For example, openings of even a single acre in size support Karner blue in New York (Schweitzer 1989), Wisconsin (Bleser 1992), and elsewhere. Nevertheless, if these small openings are isolated, resident Karner blue populations could easily be vulnerable to extinction. Therefore, small openings should not be considered as a management goal in themselves unless they are relatively close and possibly interconnected by way of dispersal corridors. In general, the smaller the opening the greater will be the required intensity of management to maintain conditions suitable for the Karner blue.

To sustain a viable metapopulation, such as the Albany Pine Bush area in New York, Givnish et al. (1988) and Schweitzer (1989, in press-a) suggest a minimum area of 2000 acres. In addition, Schweitzer (in press-a) suggests that a viable population in a pine barrens community should have a minimum of 1000 first-generation (3000-4000 second generation) Karner blue adults per deme, with at least 5 demes being present. Figures for minimum acreage and minimum population size have not yet been established for Karner blue metapopulations in oak savannas, but they are probably similar (Schweitzer in press-a). However, even populations of 1000 individuals or more are potentially at risk, as shown by the extinction of the Ontario population in 1989, which appeared linked to the drought of 1988 and the cool, wet spring of 1989 (Schweitzer in press-b, USFWS 1992).

Causes of the Rangewide Decline

Several causes have been proposed for the rangewide decline in Karner blue numbers (Packer 1987, 1990, Schweitzer 1989, 1990, in press-a, Shuey in press, USFWS 1992). Some of the principal and often interrelated causes suggested for the decline are (1) habitat loss or fragmentation, resulting from tree planting projects or through agricultural, residential, and commercial development, and (2) loss of lupine, resulting from vegetational succession due to fire suppression. In addition, often at a more local level, Karner blue populations may decline due to (3) lupine grazing by deer and other wildlife, and (4) loss of those ant species that tend and protect Karner blue larvae. Many of the above reasons have been put forward for the decline of other lupine-feeding insects (Campbell et al. 1990, Packer 1990, Shuey et al. 1987), as well as for other insects when considered in a more general sense (Greatorex-Davies et al. 1992, Murphy et al. 1990, Panzer 1988, Pyle et al. 1981). Saunders et al. (1991) review the major changes that occur in the physical environment as a result of habitat fragmentation.

As an example of habitat loss through reforestation, consider the history of establishing red pine, *Pinus resinosa*, plantations on Michigan state forest land in Region II (i.e., the upper half of Michigan's lower peninsula). During the years 1910 to 1979, an estimated 214,000 acres of state forest land were planted to red pine in Region II, with 59% of this acreage being planted between the years 1925-1940 (Haack and Mattson 1993). Much additional acreage was planted on federal lands and private lands in this area. Moreover, during these same years, thousands of additional acres were planted to jack pine and white pine, *Pinus strobus*. Practically all plantations were established on abandoned farmland and in fields and forest openings (Shuey in press). This was an especially common practice during the years of the Civilian Conservation Corps: 1933-1942 (Merrill 1981).

Several of Michigan's Karner blue sites are close to hundreds of acres of pine plantations on state and federal lands. It may be possible to log and burn selected areas in these pine plantations to create a network of sites and corridors that will subsequently be colonized by lupine, Karner blue, and other associated organisms. Restoring pine plantations to prairie or savanna with the selective use of logging and fire could serve to mimic the effects of a hot crown fire (D. Schweitzer pers. comm.).

Management Practices to Avoid

Even in areas with suitable habitat, Karner blue populations can be threatened by (1) applying herbicides that destroy lupine or nectar sources, (2) mowing during April through August, or (3) spraying insecticides that are harmful to Karner blue larvae, ants, or pollinators of the various nectar plants. In known Karner blue sites, managers should restrict the use of herbicides and insecticides along trails and roadsides.

Management Practices to Encourage

Besides the minimum acreage issues discussed above, other practices to consider in managing Karner blue preserves include: (1) establishing dispersal corridors for adults, (2) creating openings (of various configurations with islands of trees remaining to provide some shade) to promote lupine and nectaring sources, (3) converting pine plantations to prairie, (4) propagating and planting lupine and nectaring sources as needed, (5) introducing or reintroducing Karner blues and/or ants as needed, (6) using fire and/or mowing to maintain or promote lupine growth (see below), and (7) monitoring regularly populations of Karner blue, lupine, ants, and other associated sensitive species to assess the effectiveness of management treatments. In addition, private land owners should be informed about the Karner blue's presence on their properties, and they should be educated about practices that will favor the insect. Schweitzer (in press-b) provides guidelines on how to prioritize sites for protection activities. He advocates focusing on sites with more than 1000 second-generation adults per deme; where demes are or can be connected by way of foot-paths, dirt roads, or utility lines; and where a barrens/savanna community can be restored and maintained.

Fire and Mowing

Given the Karner blue's endangered status, managers will need to consult frequently with state and federal biologists and obtain necessary permits before conducting prescribed burns because such actions could result in a "take" of the species. When considering fire as a management tool, note that all life stages of the Karner blue are vulnerable to mortality from fire. Even though fast moving, patchy fires should spare some individuals, Bleser (1992) reported that Karner blue egg and larval mortality were high in spring- or fall-burned sites. It is important, states Panzer (1988), to use fire cautiously when dealing with isolated pockets of rare invertebrates.

Fire can be used both to maintain sites in early successional stages that support lupine or to restore other sites back to such a successional stage (e.g., logging followed by burning). Preserves should be divided into several fire-management units, and only one or a few burned during any single year (Lawrence and Cook 1989). Schweitzer (in press-a) advocates using fire only in sites that can be divided into three or more burn units. If possible, only a portion of each opening should be burned, with emphasis placed on areas near to active Karner blue patches but not the occupied habitat itself. Such practices will reduce Karner blue mortality within any particular site as well as reduce the flight distance required for recolonization. In Wisconsin, first-generation Karner blue adults were seen on some sites that had been burned in spring of the same year, while most burned sites were recolonized to some level during the second-generation flight (Bleser 1992). Nevertheless, several years may be needed before some burned sites are recolonized.

Prescribed burns are usually done in early spring (before mid-April) or fall (after September) when most Karner blue individuals are eggs. However, Bleser (1992) suggests that burning in August may be useful because it (1) can occur during or soon after an assessment is made of Karner blue population size and location, and (2) could allow some adults to escape the fire and oviposit elsewhere. Although true, good burning conditions are rare in August because sites are typically too moist and green. Prescribed burns would also be useful in areas that are near Karner blue sites but that do not currently support these insects. Overall, prescribed burns should be conducted in concert with Karner blue population monitoring. In isolated areas with relatively small (<100) Karner blue populations, burning should not be practiced (Schweitzer 1990, in press-a). Moreover, all proposed management plans should be reviewed by the United States Fish and Wildlife Service pursuant to Section 7 of the Endangered Species Act.

Mowing should be considered in areas that are too small for burning, where burning is difficult to accomplish, or where Karner blue populations are small and isolated. Mowing has been effective in maintaining prairie habitats (Hover and Bragg 1981, Opler 1981), and in fact, the site of the world's largest Karner blue population (at the Saratoga County Airport, New York) has been maintained entirely through mowing for the past 15 years. Schweitzer (1990, in press-a) recommends mowing from August 15 through April 15, with a minimum blade height of 4 inches and allowing the clipped vegetation to fall in place because it may contain Karner blue eggs. Waiting until late September to mow may be better, especially in cool years when development is slowed and thus oviposition is delayed.

Data Gaps

Although much is known about the Karner blue, there are still many gaps in our understanding of this insect (see Bleser 1992, Givnish et al. 1988, Packer 1990, Schweitzer 1990, in press-a,b). For example, further research is needed on:

Interaction studies

1. Karner blue performance (e.g., larval growth rate, adult fecundity) on older versus younger plants, on new versus older foliage, on fertilized versus unfertilized plants, on shaded versus open-grown plants, on plants with and without *Rhizobium lupini*, etc.);
2. Karner blue-ant interactions, the extent to which larvae need ants, which ant species best protect larvae, whether adult females oviposit preferentially in habitats occupied by certain ant species, the impact of burning on ants, and how best to promote and manage ant populations;
3. The impact of natural enemies and disease organisms on Karner blue dynamics;
4. The positive and negative aspects of gypsy moth defoliation on Karner blue and lupine dynamics;
5. The amount of canopy cover where Karner blue, lupine, and nectaring plants drop out of oak savanna, pine barrens, and other communities;
6. Identification of those habitat attributes that best predict Karner blue occupancy and reproductive success;
7. The relations between lupine, Karner blue, and various ant species with soil, weather, and landform gradients;
8. A landscape-level analysis of Karner blue and lupine sites, using GIS and various ecological classification systems;

Karner blue issues

9. Development of Karner blue life tables for different habitat types;
10. Dispersal and recolonization capabilities of Karner blue adults and barriers to their dispersal (see Givnish et al. 1988);
11. Methods to propagate, transport, and introduce Karner blue life stages into the field;
12. Whether any cluster of Karner blue populations is still behaving as a metapopulation;
13. The optimal size, spatial configuration, and juxtaposition of Karner blue sites to best promote a functioning metapopulation;
14. Fine-tuning of techniques to estimate Karner blue population size, including follow-up monitoring after initial surveys are conducted;
15. What constitutes the minimum viable population size (including population viability analysis; Boyce 1985), minimum habitat area, and critical habitat;
16. The susceptibility of Karner blue to *Bt* insecticidal sprays;
17. Historical studies that document long-term Karner blue population fluctuations in relation to weather and management practices.

Lupine issues

18. The life cycle and requirements of lupine and its associated *Rhizobium*, how long lupine lives and how seeds are dispersed, when to burn/mow to best promote lupine, how to best propagate and seed lupine, and what other herbivores feed on lupine;

Other biological and managerial issues

19. The genetic structure of Karner blue, lupine, and *Rhizobium lupini* populations; and
20. Setting specific guidelines as to which sites to burn, mow, or conduct other management practices, when to do these activities, and how often to repeat them to enhance survival and recovery of Karner blue and other associated sensitive species;

ACKNOWLEDGMENTS

The author thanks Michael Amaral, Cathy Bleser, Rex Ennis, Bill Gabbert, Michelle Grigore, Joe Kelly, Susan Lauzon, Mark Leach, Deborah McCullough, Paul Opler, Laurence Packer, Cathy Papp, Mary Rabe, Don Riemenschneider, Dolores Savignano, Nancy Sferra, Dale Schweitzer, and Leni Wilsmann for their critical reviews of an earlier draft of this manuscript; and Cathy Bleser, George Heaton, Judith Maxwell, and Brent Sieling for compiling much of the lupine range data.

LITERATURE CITED

Atstatt, P.R. 1981a. Lycaenid butterflies and ants: selection for enemy-free space. Amer. Nat. 118:638-654.

Atstatt, P.R. 1981b. Ant-dependent food plant selection by the mistletoe butterfly *Ogyris amaryllis* (Lycaenidae). Oecologia 48:60-63.

Ballard, H., and N. Sferra. 1991. Distribution and management of an indicator species of oak savannas, the Karner blue butterfly (*Lycaeides melissa samuelis*): Post-treatment population studies. Unpublished report, The Nature Conservancy, East Lansing, MI. 9p. + tables.

Bess, J.A. 1989. Status of the Karner blue butterfly, *Lycaeides melissa samuelis* Nabokov, in the Manistee National Forest. Unpublished report, Michigan Natural Features Inventory, Lansing, MI. 20p.

Bidwell, A.D. 1991. A habitat-based preserve plan for the Karner blue butterfly (*Lycaeides melissa samuelis*) in Concord, New Hampshire. Unpublished report, The Nature Conservancy, New Hampshire Field Office. 37p.

Bleser, C.A. 1990. The Wisconsin 1990 status survey for the Karner blue butterfly (*Lycaeides melissa samuelis*). Unpublished report, Wisconsin Department of Natural Resources, Bureau of Endangered Resources, Madison, WI. 27p.

Bleser, C.A. 1992. Status survey, management and monitoring activities for the Karner blue butterfly (*Lycaeides melissa samuelis*) in Wisconsin, 1990-1992. Unpublished report, Wisconsin Department of Natural Resources, Bureau of Endangered Resources, Madison, WI. 88p. + appendices.

Boyce, M.S. 1992. Population viability analysis. Annu. Rev. Ecol. Syst. 23:481-506.

Boyonoski, A.M. 1992. Factors affecting the establishment and maintenance of *Lupinus perennis* (wild lupine). M.S. thesis, University of Guelph. Guelph, Ontario.

Campbell, C.A., D.P. Coulson, and A.A. Bryant. 1990. Status, distribution and life history characteristics of some butterflies at risk in th Carolinian forest zone of Ontario. In G.M. Allen, P.F.J. Eagles, and S.D. Price (eds.), Conserving Carolinian Canada, p. 207-252. Waterloo, Ontario: Univ. Waterloo Press.

Cryan, J.F. 1980. The Karner blue butterfly (*Lycaeides melissa samuelis* Nabokov) in Hudson Valley sand belt of New York State. Part II. An annotated list of Hudson Valley sand belt populations and their status. Unpublished report, New York State Department of Environmental Conservation, Endangered Species Unit. 31p.

Cryan, J.F., and R. Dirig. 1978. A report on the status of the Karner blue butterfly (*Lycaeides melissa samuelis* Nabokov) in New York State. Unpublished report, New York State Department of Environmental Conservation. 18p.

Cuthrell, D.L. 1990. Status of the Karner blue butterfly, *Lycaeides melissa samuelis* Nabokov, in Minnesota, 1990. Unpublished report, Minnesota Department of Natural Resources, Nongame Wildlife Program. 44p.

DeVries, P.J. 1988. The larval ant-organ of *Thisbe irenea* (Lepidoptera: Riodinidae) and their effects upon attending ants. Zool. J. Linnean Soc. 94:379-393.

DeVries, P.J. 1989. Detecting and recording the calls produced by butterfly caterpillars and ants. J. Res. Lepid. 28:258-262.

DeVries, P.J. 1992. Singing caterpillars, ants and symbiosis. Sci. Amer. 267(October):76-82.

Dirig, R. 1973. The endangered Karner blue. The Conservationist 28:6,47.

Dirig, R. 1988. Nabokov's blue snowflakes. Nat. Hist. 97:68-69.

Dirig, R., and J.F. Cryan. 1976. The Karner Blue Project: January 1973 to December 1976. Atala 4:22-26.

Downey, J.C. 1966. Distribution of Lycaenidae (Lepidoptera) in Illinois. Illinois Acad. Sci. Trans. 59:163-168.

Ewert, D.N., and H.E. Ballard, Jr. 1990. Distribution and management of an indicator species of oak savannas, the Karner blue butterfly (*Lycaeides melissa samuelis*): Preburn population studies. Unpublished report, The Nature Conservancy, East Lansing, MI. 10p.

Givnish, T.J., E.S. Menges, and D.F. Schweitzer. 1988. Minimum area requirements for long-term conservation of the Albany Pine Bush and Karner blue butterfly: an assessment. Unpublished report to the City of Albany from Malcolm Pirnie, Inc. Albany, NY. 95p. + figures.

Greatorex-Davies, J.N., M.L. Hall, and R.H. Marrs. 1992. The conservation of thepearl-bordered fritillary butterfly (*Boloria euphosyne* L.): preliminary studies on the creation and management of glades in conifer plantations.

Grigore, M. 1992. The short-term effect of fire on wild lupine (*Lupinus perennis* L.). M.S. thesis, University of Toledo. Toledo, Ohio. 73p.

Haack, R.A. 1992. Endangered and threatened insects in the United States and Michigan. Newsletter Mich. Entomol. Soc. 37(2&3):1-8.

Haack, R.A. and W.J. Mattson. 1993. Life history patterns of North American tree-feeding sawflies. In M.R. Wagner and K.F. Raffa (eds.), Sawfly Life History Adaptations to Woody Plants, p. 503-545. Orlando, FL: Academic Press.

Helmboldt, K.M. and M. Amaral. 1992. Status of the Karner blue butterfly in New Hampshire. Unpublished report, The Nature Conservancy, New Hampshire Field Office, Concord, NH and U,S. Fish and Wildlife Service, New England Field Office, Concord, NH. 7p.

Hover, E.I., and T.B. Bragg. 1981. Effect of season of burning and mowing on aneastern Nebraska *Stipa-Andropogon* prairie. Amer. Midl. Nat. 105(1):13-18.

Jordano, D., J. Rodriquez, C.D. Thomas, and J. Fernandez Haeger. 1992. The distribution and density of a lycaenid butterfly in relation to *Lasius* ants. Oecologia 91:439-446.

Konecny, A. 1986. A Status Report on the Karner Blue Butterfly (Lycaeides melissa samuelis Nabokov) in Canada. Unpublished report to the Ontario Ministry of Natural Resources. 48p.

Krombein, K.V., P.D. Hurd, D.R. Smith, and B.D. Burks (Eds.). 1979. Catalog of Hymenoptera in America North of Mexico, Vol. 1, p. 246, 541, 619-620. Smithsonian Institution Press, Washington, D.C.

Lane, C.P. 1992. The status of the Karner blue butterfly (*Lycaeides melissa samuelis*: Lycaenidae) and associated plant resources in Minnesota, 1991. Unpublished report, Minnesota Department of Natural Resources, Nongame Wildlife Program. 36p.

Lawrence, W.S., and A.C. Cook. 1989. The status and management of Karner blue (Lycaeides melissa samuelis) populations in the Allegany State Game Area, Michigan. Unpublished report, Nature Conservancy, Michigan Field Office, East Lansing, MI. 65p.

Leach, M. 1993. Status and distribution of the Karner blue butterfly at Fort McCoy, Wisconsin: Final report on a two-year study. Unpublished report prepared for the Natural Resources Management Division, Fort McCoy Military Reservation, U.S. Army. The Nature Conservancy, Wisconsin Chapter. 50p. + 27p appendix.

Magdich, M.L. 1989. A survey of Karner blue (*Lycaeides melissa samuelis* (Nabokov) populations in the oak openings of northwestern Ohio. Unpublished report, Ohio Department of Natural Resources, Columbus, OH. 47p.

Maschwitz, U., M. Wust, and K. Schurian. 1975. Blues' larvae as sugar suppliers for ants. Oecologia 18:17-21. (in German)

Martin, M.L. 1992. Karner blue butterfly (*Lycaeides melissa samuelis*) in Indiana: 1990 status report. Unpublished report, Indiana Department of Natural Resources, Indianapolis, IN. 13p.

Masters, J.H., and F.H. Karpuleon. 1975. Records of *Lycaeides melissa samuelis* (Lycaenidae) from Wisconsin. J. Lepid. Soc. 29:31.

Merrill, P.H. 1981. Roosevelt's Forest Army: A History of the Civilian Conservation Corps, 1933-1942. Montpelier, VT: published by the author.

Murphy, D.D., K.E. Freas, and S.B. Weiss. 1990. An environment-metapopulation approach to population viability analysis for a threatened invertebrate. Conservation Biol. 4:41-51.

Nabokov, V. 1943. The Nearctic forms of *Lycaeides* Hub. (Lycaenidae, Lepidoptera). Psyche 50:87-99.

Nuzzo, V.A. 1986. Extent and status of midwest oak savanna: presettlement and 1985. Natural Areas J. 6(2):6-36

Opler, P.A. 1981. Management of prairie habitats for insect conservation. J. Natural Areas Assoc. 1(4):3-6

Opler, P.A. 1985. Extirpated Karner blue butterfly. In H.H. Genoways and F.J. Brenner (eds.), Species of Special Concern in Pennsylvania, Special Publ. 11, p. 162-163. Pittsburgh, PA: Carnegie Museum of Natural History.

Opler, P.A. and G.O. Krizek. 1984. Butterflies East of the Great Plains, p. 120-121. Baltimore, MD: John Hopkins Univ. Press.

Packer, L. 1987. Status report on the Karner blue butterfly, *Lycaeides melissa samuelis* Nabokov, in Canada. Unpublished report for the World Wildlife Fund and the Ontario Ministry of Natural Resources, Wildlife Branch, Nongame Program. 66p.

Packer, L. 1990. The status of two butterflies, Karner blue (*Lycaeides melissa samuelis*) and frosted elfin (*Incisalia irus*), restricted to oak savanna in Ontario. In G.M. Allen, P.F.J. Eagles, and S.D. Price (eds.), Conserving Carolinian Canada, p. 253-271. Waterloo, Ontario: Univ. Waterloo Press.

Panzer, R. 1988. Managing prairie remnants for insect conservation. Natural Areas J. 8:83-90.

Peterson, M.A. 1993. The nature of ant attendance and the survival of larval *Icaricia acmon* (Lycaenidae). J. Lepid. Soc. 47:8-16.

Pierce, N.E. and S. Easteal. 1986. The selective advantage of attendant ants for the larvae of a lycaenid butterfly, *Glaucopsyche lygdamus*. J. Anim. Ecol. 55:451-462.

Pierce, N.E. and M.A. Elgar. 1985. The influence of ants on host plant selection by *Jalmenus evagoras*, a myrmecophilous lycaenid butterfly. Behav. Ecol. Sociobiol. 16:209-222.

Pyle, R., M. Bentzien, and P. Opler. 1981. Insect conservation. Annu. Rev. Entomol. 26:233-258.

Rohlf, D.J. 1989. The Endangered Species Act. Stanford Law School, Stanford, CA.

Saunders, D.A., R.J. Hobbs, and C.R. Margules. 1991. Biological consequences of ecosystem fragmentation: a review. Conservation Biol. 5(1):18-32.

Saunders, W. 1878. Notes on the larva of *Lycaena scudderi*. Can. Entomol. 10:14-15.

Savignano, D.A. 1990. Field investigations of a facultative mutualism between *Lycaeides melissa samuelis* Nabokov (Lycaenidae), the Karner blue butterfly, and attendant ants. Ph.D. Dissertation. Univ. Texas, Austin. 120p.

Schweitzer, D.F. 1989. Fact sheet for the Karner blue butterfly with special reference to New York. Unpublished report, The Nature Conservancy. 7p.

Schweitzer, D.F. 1990. The 1990 status of selected Karner blue remnants in Saratoga and Albany counties, New York with a discussion of monitoring methods. Unpublished report, New York Department of Environmental Conservation, Endangered Species Unit. 23p.

Schweitzer, D.F. 1993a. Recovery goals and methods for Karner blue populations. In D.A. Andow, R.J. Baker, and C.P. Lane (eds). Karner Blue Butterfly: a symbol of a vanishing landscape, 22-24 April 1992, Zanesville, OH. University of Minnesota Agricultural Experiment Station, St. Paul, MN. (In press)

Schweitzer, D.F. 1993b. Prioritizing Karner blue (*Lycaeides melissa samuelis* Nabokov) habitats for protection activities. In D.A. Andow, R.J. Baker, and C.P. Lane (eds). Karner Blue Butterfly: a symbol of a vanishing landscape, 22-24 April 1992, Zanesville, OH. University of Minnesota Agricultural Experiment Station, St. Paul, MN. (In press)

Scudder, S.H. 1888. Feeding habits of a lycaenid caterpillar. Psyche 5:13.

Scudder, S.H. 1889. The Butterflies of Eastern United States and Canada with special reference to New England. Cambridge, MA. pp. 964-969.

Sferra, N.J. and T. Darnell. 1992. Distribution and management of the Karner blue butterfly (*Lycaeides melissa samuelis*) in Newaygo and Muskegon Counties, Michigan. Unpublished report, The Nature Conservancy, Michigan Field Office, East Lansing, MI. 17p.

Shapiro, A.M. 1974. Partitioning of resources among lupine-feeding Lepidoptera. Am. Mid. Nat. 91:243-248.

Shuey, J.A. In press. Dancing with fire: Ecosystem dynamics, management, and the Karner blue (*Lycaeides melissa samuelis* Nabokov). In Proceedings of the midwest oak savanna conference, 20 February 1993, Chicago, IL. U.S. Environmental Protection Agency, Chicago.

Shuey, J.A., J.V. Calhoun, and D.C. Iftner. 1987. Butterflies that are endangered, threatened, and of special concern in Ohio. Ohio J. Sci. 87(4):98-106.

Shull, E.M. 1987. The Butterflies of Indiana, p. 163-164. Bloomington & Indianapolis, IN: Indiana Press.

Smallidge, P.J. and D.J. Leopold. Environmental factors and critical for *Lycaeides melissa samuelis* along transmission line rights-of-way in east-central New York, USA. In preparation.

Smiley, J.T., P.R. Atstatt, and N.E. Pierce. 1988. Local distribution of the lycaenid butterfly, *Jalmenus evagoras*, in response to host ants and plants. Oecologia 76:416-422.

Stone, A., C.W. Sabrosky, W.W. Wirth, R.H. Foote, and J.R. Coulson (Eds.). 1983. A Catalog of the Diptera of America North of Mexico, p. 1098. Washington, D.C.: Smithsonian Institution Press.

USFWS (United States Fish and Wildlife Service). 1992. Endangered and threatened wildlife and plants; determination of endangered status for the Karner blue butterfly. Federal Register (December 14, 1992). 57(240):59236-59244.

Wilcove, D.S., M. McMillan, and K.C. Winston. 1993. What exactly is an endangered species? An analysis of the U.S. endangered species list: 1985-1991. Conservation Biol. 7(1):87-93.

Wilsmann, L. 1992. Karner blue. *Lycaeides melissa samuelis* Nabokov. Unpublished draft report, Michigan Department of Natural Resources, Wildlife Division. 7p.

A Graphic Technique for Identifying Superior Seed Sources for Central Hardwoods

Fan H. Kung and George Rink[1]

To maximize forest production, foresters need to plant the best genotypes provided by forest geneticists. Where should the forest geneticist search for the best seed sources? How far can one go south, or north to find them? The answer may rely on the species and the location of the test plantation. For example, when black walnut trees were tested in Illinois, Indiana, Missouri, and southern Michigan, trees from southern seed sources grew faster than those of local and northern seed sources. However, in Iowa and Minnesota, trees from northern sources were generally larger than trees from southern sources, and in Kansas and Ohio, tree size was not associated with latitude of seed source (Bey 1973, 1979). As the number of plantation increases, we may find that the most southern plantation will have only northern seed sources and the most northern plantation will have only southern seed sources, we may not be able to make a simple statement as to the best seed zone for each plantation location. Since a picture is better than a thousand words, we suggest a simple graphic solution useful to answer these questions.

METHOD AND PROCEDURE

The procedure can be summarized as follows. Seed sources are first selected according to their standardized performance. Their position is plotted on a diagram using latitude of the plantation as the x-coordinate and the difference between provenance latitude and plantation latitude as the y-coordinate. Employing this graphic technique, probable locations for superior genotypes can be easily defined.

To illustrate the procedure with a practical example, we applied this technique to data from 12- and 13-year-old rangewide provenance/progeny tests of white ash planted at 12 locations throughout the eastern United States (Table 1). The average tree height of each provenance is first standardized according to the plantation mean and standard deviation among provenances in that plantation, so that after standardization the distribution of provenance performances in each plantation will have zero mean and unit variance. The standardization is necessary for valid performance comparisons.

The next step is to define superior seed sources. To make sure that the seed sources we have selected will have at least one standard selection differential above the plantation mean, we intentionally discard those with standardized scores of less than one. This level of selection intensity allows us to retain about 15% of the seed sources. The most probable geographic searching areas then will be delineated by these top 15% seed sources.

---

[1] Professor, Department of Forestry, Southern Illinois University, Carbondale, IL 62901; and Principal Research Geneticist, USDA Forest Service, North Central Forest Experiment Station, Carbondale, IL 62901.

Table 1.—Height of white ash at various provenance and plantation combinations. The original data are sorted from top to bottom by latitude of provenance in descending order, and sorted from left to right by latitude of plantation in ascending order.

Provenance					Plantation												Mean
State	No.	Lat.	Long.	Elev.	LA	AL	AR	IL	IN	KY	WV	KS	OH	NE	MI	WI	
		-.1 Deg-		Ft.	-Height in cm.-												
MI	6736	466	896	1300	125			550	200			241	785	298	546	297	380
NBR	6807	460	673	500											615		615
NBR	6804	459	661	50				540							481		511
WI	6723	457	890	1675	138			590	154	291	295	258	861	313	631	276	381
ONT	6796	456	767	300				584									584
ONT	6731	456	771	590											612		612
QUE	6808	455	742	48										347	591		469
MI	6780	454	849	800									849		632		741
MI	6779	453	836	640	144			567				233	745		567	252	418
ME	6785	449	686	100	233			561	60	250			743	247	565		380
ME	6786	447	687	240							269	243				205	239
MI	6802	445	857	1060								313					313
VT	6782	440	729	1700	109			539						377	631		414
VT	6788	429	729	1400			366										366
NY	6793	428	761	1640					188	354	508	291		319	647	262	367
MI	6769	422	837	850				598				302		338	623		465
CT	6724	414	728	350				551	120				827	331	621		490
CT	6794	413	730	210	160			644		254	313		722	221	542		408
PA	6725	408	780	1175											591		591
OH	6732	407	819	1059							376	244	847	386	559	316	455
NE	6720	406	957	900			275		233	353	280	458		371	581	415	371
IL	6726	397	912	700				656	357		400	372		331	589	242	421
OH	6739	396	847	1000					400			419	907	386			528
WV	6806	392	801	1300							481			372	549		467
OH	6798	392	841	956						393					621		507
IL	6771	391	884	590	275		289	738	368	454	384	292	916	393	503	242	441
WV	6778	391	796	2500	151			580			479	297	820				465
IN	6795	380	862	650	279		149	802	252	330	441	440	1000	342	644	261	449
IL	6721	377	893	477	362			844	376	494	418	383	858	321	512		508
IL	6722	376	883	500		618	282					331				266	374
KY	6792	372	874	500	336	622	245	790				376	906	324	524	261	487
KY	6799	372	830	1250						446							446
KY	6734	369	882	495	348			834	379	451	306		933	382	605		530
MO	6727	367	911	847				845						354	471		557
TN	6865	365	858	980												258	258
TN	6868	365	875	650					376	477						208	354
TN	6864	365	854	1170					344	454	296	358				239	338
TN	6866	365	886	350			245		432								339
AR	6735	364	929	885		635	322		307	381	357	342		321	585	228	386
TN	6870	364	837	1050		688	239										464
NC	6797	358	786	350										367	598		483
TN	6862	357	842	980					298	443	287	345				207	316
NC	6783	357	826	2400											550		550
TN	6871	355	852	1100	368	610		814				335					532
TN	6873	354	867	800		618	287				324			349	534		422
TN	6874	353	850	760		722											722
TN	6728	352	859	1110	312	676	211	729	276	376	319	310		292	553	216	388
TN	6861	351	872	900		650	243			438						233	391
SC	6784	350	830	750								268				232	250
TN	6872	350	847	830		656	234							356	628		469
GA	6781	348	839	3000								310					310
AR	6790	346	936	700		701	299										500
AL	6733	345	865	1000	317	652	266	707	346	394	263		847	354	529		468
MS	6730	339	889	200				787									787
MS	6740	334	888	380	473	692	290	898	356	456	289	267	591			206	452
LA	6738	315	910	30	548	935	476	603	361	362	358	268	417				481
MS	6737	310	888	250	473	843	410	681	330	447		286	435	206	329		444
TX	6768	303	944	100	488	868	448	680		337			392				536
Mean					297	699	293	681	296	393	354	318	770	333	569	253	
Lat.					304	324	346	375	381	382	390	391	400	405	423	430	

Once the superior seed sources are identified, we subtract the plantation latitude from provenance latitude, so that the latitude of the seed source is transformed to a relative scale in reference to the plantation. Positive sign indicates northern seed source and negative sign represents southern seed sources. The difference was used as the y-coordinate and the latitude of the plantation was used as the x-coordinate of the selection. The positions then were plotted (Figure 1a).

In order to generalize the application of the technique to the high-value central hardwood, results from a 22-year-old, 7-plantation black walnut provenance/progeny test are also presented (Figure 1b). Data for black walnut were obtained from Bresnan (personal communication) and were summarized in Table 2.

DISCUSSION OF METHOD

Due to differences in genotype stability, it seems probable that plantation means, and the variance of provenance performances in different plantations, will not be equal. Standardization allows us to compare selections on a common base. However, in the case of equal variances but unequal means, the original data can be transformed to percent of plantation mean to facilitate comparison. To most people, it is easier to visualize percentage gain than gain in standard units. The question "If I want the seed sources that are 20% better than the average, where can I find them?", is more pragmatic than a similar question "If I want the seed sources which have a selectional differential of 1.4 unit, where can I find them?"

To answer the last question above, we arbitrary set the cut-off point of selection at one standard unit. The reader is free to choose some other selection intensity or selection proportion to meet the need of a particular tree improvement program. Too few or too many selections usually make the seed collection zone less clearly defined.

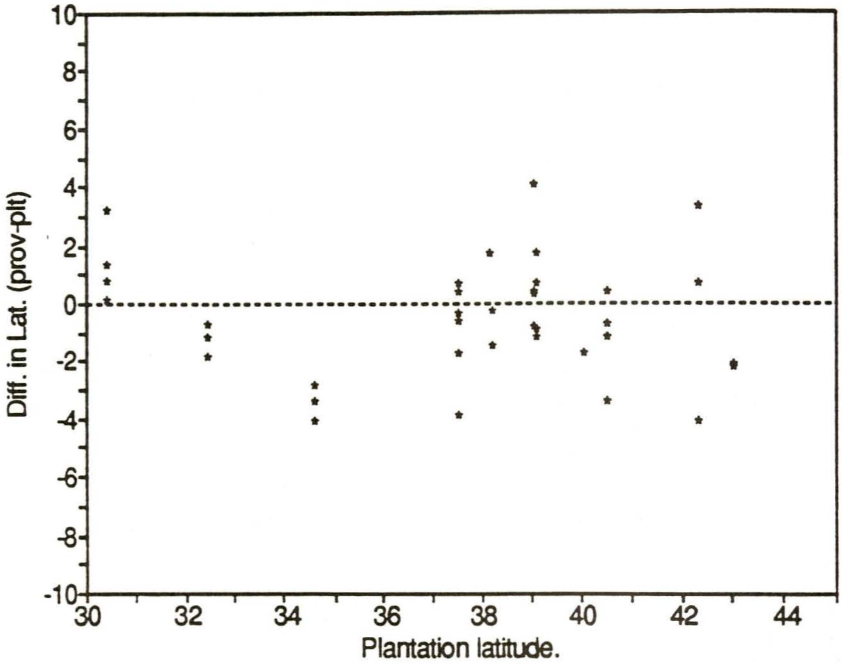
We used latitude as an independent variable because our data indicates that correlation is strongest between height growth and latitude, but is weak between height and degrees of longitude or elevation. However, readers may find the use of some other variables would be more meaningful for their models, for example, the variable minimum temperature at the source as deviation from that of the planting site may be of interest (Schmidtling, 1992). Minimum temperature is related to many climatic variables such as average temperature, number of frostfree-days, and number of degree-days; and to many geographic variables such as longitude, latitude, and elevation.

DISCUSSION OF RESULTS

The attraction of such a graphical approach results from the ease of making predictions about where to look for the superior seed sources in a given untested location. For example, if you want to find a good white ash seed source for planting at 31 degrees north latitude, Figure 1a shows that you have a better chance by going north. If you want to plant white ash at 38 degrees north, you may find them within 2 degrees latitude of the planting areas.

As seen in Figure 1a, there are 23 asterisks above the zero line, the probability of finding a superior white ash is 23 out of 38, or 61% south of the planting site, and 15 out of 38, or 39% north of the plantation. In other words, it is 1.6 times (61%/39%) more likely to find a good seed source from the south than that from the north. The "odds ratio" of finding a good seed source from the south than that from the north is therefore 1.6. The odds ratio is even higher for black walnut trees (5:3:1). However, one must keep in mind that the experimental design and sampling procedure contribute to the outcome of finding the good seed sources. When a plantation is located at the southern perimeter of the species distribution range, such as the Louisiana plantation for

1a) White Ash



1b) Black Walnut

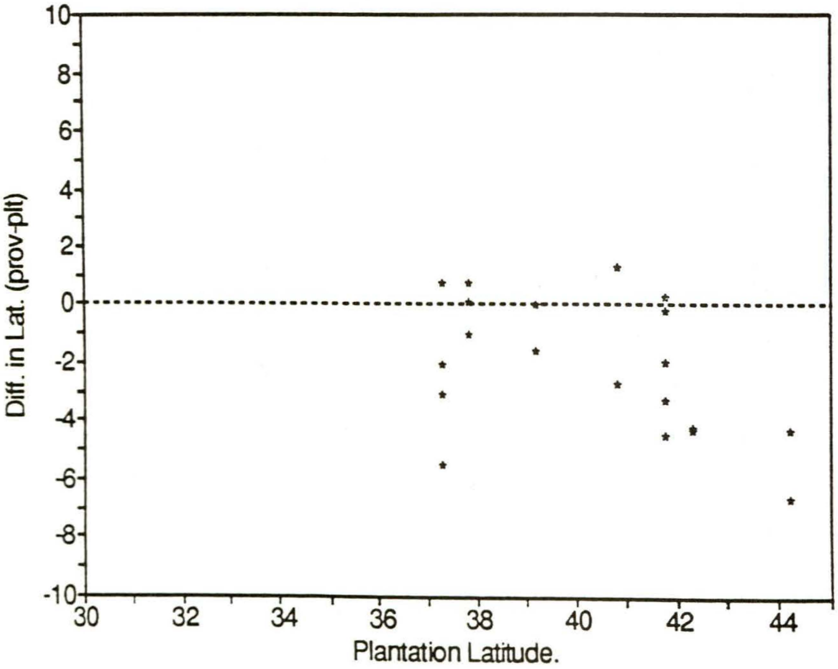


Figure 1.—Location of the top 15% provenances in each plantation.

Table 2.—Height of black walnut at various provenance and plantation combinations, sorted by latitude of provenance and by latitude of plantation

Provenance					Plantation							
State	**No.**	**Lat.**	**Long.**	**Elev.**	**IL**	**MO**	**KS**	**OH**	**IA**	**MI**	**MN**	**MEAN**
MN	2503	44.4	94.5	1000						103		103
MN	2501	43.6	92.3	1300							69	69
HI	2406	43.1	85.7	800							75	75
IA	1807	42.8	92.8	950					75			75
IA	1809	42.5	96.4	1100					72			72
HI	2405	42.5	83.8	850						121		121
IA	1803	42.3	91.2	900	60		143			108		104
IA	1801	42.1	93.6	950							71	71
HI	2403	42.0	85.7	840				120	64	114		99
IL	1607	41.9	89.3	790				135				135
IA	1802	41.8	91.9	700		81			82		74	79
IL	1602	41.5	90.4	600						122		122
IL	1605	41.4	88.1	610	56				81			69
IL	1603	41.2	89.2	700							71	71
PA	3502	41.0	77.1	640				130		123		127
IA	1810	40.7	95.7	1100							48	48
IA	1805	40.7	92.5	950	55							55
IN	1705	40.2	86.9	600					71		70	71
OH	3202	40.1	84.7	1000				132				132
PA	3503	40.0	77.1	640				124	65			95
OH	3201	39.8	84.6	920							71	71
IN	1702	39.8	86.9	730				129		112		121
MO	2705	39.7	91.4	660							86	86
MO	2702	39.6	94.7	878		86			81			84
IN	1707	39.3	85.0	950		79						79
KS	1903	39.1	94.9	900			159	131		115		135
KS	1901	39.1	96.1	1050					78			78
IN	1709	39.1	86.9	490	70	75						73
IN	1704	39.0	86.1	780			161			118		140
IN	1701	38.7	86.5	640				120	63		79	87
OH	3203	38.6	82.6	600					77			77
MO	2708	38.3	94.1	800	71				80			76
KS	1902	38.3	95.2	975		92	159				54	102
IN	1708	38.2	86.5	775	61		148	124	59	112		101
KY	2002	38.0	83.5	1000						121	44	83
MO	2703	37.9	93.9	925				134		119		127
WV	4202	37.9	80.2	1950				135		140	73	116
VA	4101	37.8	79.5	1000	78				65	132		92
KY	2005	37.6	84.3	1100	59			131				95
MO	2704	37.6	91.5	1170		93						93
VA	4102	37.5	80.1	1450				127				127
IL	1601	37.4	89.3	540	71				60		94	75
MO	2706	37.4	91.0	795				124				124
KS	1904	37.3	94.8	875			161					161
VA	4104	37.1	76.9	120				130	82			106
KY	2004	37.0	84.3	1150	67			123		120		103
KY	2001	36.9	86.8	520		76				120		98
VA	4103	36.9	78.7	460			149	122	38	124		108
KY	2003	36.7	84.1	1700			150		59		51	87
MO	2707	36.6	94.4	900		93	158		70			107
TN	3804	36.4	82.0	2040		77	145	125		112		115
TN	3805	36.4	8.4	650				122				122
TN	3803	36.3	83.7	1275	60	71		130	63	125		90
NC	3101	36.0	81.7	1500	76			125	62		74	84
AR	1101	35.8	92.3	1200	64	74	159		73			93
NC	3105	35.5	82.6	2200	72		155		41			89
NC	3102	35.4	83.7	2900	66	68				127		87
NC	3103	35.3	82.8	2500				130	62			96
TN	3802	35.2	85.9	1700				130				130
TN	3806	35.2	88.3	480	78							78
AR	1102	34.9	93.9	1916	60							60
MS	2602	34.0	88.9	400	81	85	147					104
SC	3601	33.9	82.1	510			136	114				125
MS	2601	32.3	89.4	450	68	83		90				80
TX	3901	31.6	96.0	360	90							90
TX	3902	31.5	94.6	308		72						72
TX	3903	31.1	94.9	260			143					143
Mean					68	80	152	125	68	119	69	96
Lat.					37.3	37.8	39.2	40.8	41.8	42.3	44.2	

white ash, only the northern seed sources are available for selection; consequently no southern seed sources can be selected. On the opposite extreme, in Minnesota, only southern black walnut seed sources are available; no northern seed sources can be selected. A valid argument in favor of the southern or northern provenances can be made only when equal numbers and equal ranges of southern and northern provenances are present at the same plantations.

The probability of finding a good seed source from the south is more consistent in black walnut than that in white ash. In all seven black walnut plantations, the southern seed sources outnumber or equal the northern seed sources in selected numbers. But in the white ash study, in three (LA, WV and MI) out of the 12 plantations the northern seed sources provide better results. Therefore it can be said that there are more plantation-by-provenance interactions in white ash than in black walnut. In a previous analysis we found that the variance component for the plantation-by-provenance interaction was 5% for black walnut (Kung and Smith, 1989), and 8% for white ash (Kung and Clausen, 1983).

When the "local seed source" is defined as a provenance within 200 miles of the plantation, most of selections are local. Black walnut and white ash trees seem to be well acclimated or adapted to local environments on the basis of tree height.

CONCLUSIONS

The application of this graphic technique is mainly for provenance tests planted in many locations. The technique enables visualization of the pattern of locations for superior seed sources. Foresters can use it as a guide to find the best seed source for the planting location.

LITERATURE CITED

Bey, C.F. 1973. Growth of Black walnut trees in eight midwestern States - a provenance test. North Cent. For. Exp. Stn., St. Paul, Minn. 7 p., illus. (USDA For. Serv. Res. Pap. NC 91).

Bey, C.F. 1979. Geographic variation in Juglans nigra in the midwestern United States. Silvae Genetica 28:132-135.

Bresnan D.F., G. Rink, I.F. Diebel and W.A. Geyer. 1993. Black walnut provenance performance at seven plantations at age 22. Manuscript under preparation.

Kung, F.H. and K.E. Clausen. 1983. Genetic x environment interaction in white ash. Proc. North Central For. Tree Improv. Conf. 3:228-232.

Kung, F.H. and G. Smith. 1989. Provenance and plantation interaction in black walnut. Proc. Black Walnut Symposium. 4:153-158.

Schmidtling R.C. 1992. A minimum temperature model for describing racial variation in loblolly pine provenance tests. Proc. North Amer. For. Biol. Workshop, 12:124.

Phenology and Recruitment of Ohio Buckeye and Sugar Maple in Illinois Forest Stands

Michelle Henderson, Jeffrey O. Dawson, and Evan H. DeLucia[1]

Abstract: Phenological patterns, light conditions, and photosynthetic activity of Ohio buckeye and sugar maple foliage on trees in the forest understory were monitored and compared over two growing seasons in two mesophytic upland woodlands in central Illinois. Ohio buckeye began leaf expansion three to four weeks earlier than sugar maple, started leaf senescence and shedding in July, and had lost all leaves by September 1. Sugar maple began senescence in September and lost its leaves by the end of October. Thirty percent area inventories of both Ohio buckeye and sugar maple vegetation on both 24-hectare forests were performed to determine recruitment from small size classes to larger size classes. Ohio buckeye had large numbers of seedlings in the 0-2 cm stem diameter class (990 and 1,032 stems/ha), but far fewer saplings and trees. Buckeye distribution was patchy and concentrated in gaps and along the edges of the forest. Sugar maple had more small seedlings than Ohio buckeye (2,767 and 1,311 stems per ha <2 cm stem diameter) and more saplings and trees than buckeye. Maples were more evenly distributed throughout the forest. During July with understory light intensities less than 50 umol/m^2/sec PAR, understory sugar maple net photosynthesis averaged 4-5 umol/m^2/sec CO_2 while Ohio buckeye rates were always less than 1. This study suggests that Ohio buckeye takes advantage of high light levels in the spring to acquire much of its carbon, as is the case with spring ephemerals, and differs from sugar maple in its adaptation to limited light.

INTRODUCTION

In the mixed upland forests of central Illinois, the first woody plant to produce leaves is Ohio buckeye (*Aesculus glabra*). It is also the first to lose its leaves. Ohio buckeye is generally a medium-sized tree found on moist sites along streambanks and river bottoms in the central United States. It can be found on drier sites, mixed with oak-hickory or beech-maple stands, but there it is usually smaller and slower-growing and seldom becomes dominant. Because it often grows in the Beech-Sugar Maple Type, it is considered intermediate to high in shade tolerance. As it is usually the first tree to leaf out in early spring, leaves are sometimes killed by frost, although frost does not seem to damage the tree. Ohio buckeye seems to be very tolerant of severe winters, and has been successfully introduced in Minnesota and Massachusetts (Fowells, 1965). The flowers of the buckeye appear after the leaves in the spring. The fruit, which is a leathery capsule that may contain 1 to 3 seeds, ripens from September to October. Germination occurs in the spring, and Ohio buckeye generally develops a strong taproot the first year.

Sugar maple (*Acer saccharum*) is one of the largest and most important hardwoods in the eastern United States. It has a broad range, including the eastern part of the United States and also southern Canada. Sugar maple grows best on fertile, moist, and well drained soils. It will grow on poor, dry, shallow soils, but will not thrive. Sugar maple is a very shade tolerant species, able to withstand years of suppression (Fowells, 1965). In the midwest, sugar maple generally begins to leaf out in mid April, and the tree is in full leaf in approximately three to four weeks. The flowers are usually in full bloom within a week after emerging. The fruit is a double samarra which ripens in about 12 weeks, and begins to fall about 2 weeks after ripening. Sugar maples produce large quantities of seed, so although in some years seedling mortality may be high, enough seed is usually produced to ensure sufficient regeneration (Hett and Loucks, 1971).

---

[1] Department of Forestry, University of Illinois, W-503 Turner Hall, Urbana, IL 61801.

In previous studies in east central Illinois, sugar maple was the dominant tree species in all diameter size classes below 60 cm in two upland woodlands, with Ohio buckeye being a major component of the seedling and sapling size classes (Edgington, 1991; Pelz and Rolfe, 1977). Although there were large numbers of small diameter buckeyes, there were fewer trees in the larger diameter size classes than might be expected. In these woodlands Ohio buckeye is the first woody plant to leaf out in the early spring, typically about four weeks before canopy closure, and one to two weeks before other woody species. It begins senescence in early July, when the canopy is fully closed. Thus perhaps Ohio buckeye avoids shade rather than tolerating it, in a manner similar to the spring ephemeral herbs.

This was found to be the case for a related species, the Georgia buckeye (*Aesculus sylvatica*). DePamphilis and Neufeld (1988) found that the Georgia buckeye produced leaves in mid March and began senescence in June, soon after canopy closure, with complete senescence by September 1. They measured light levels, which declined from 74% of full sun in March to 4% after canopy closure in May. Leaves began senescence at that time, as indicated by declining levels of chlorophyll-a together with leaf nitrogen loss and leaf discoloration. It was concluded that the Georgia buckeye behaved like a woody analog of shade-intolerant spring ephemeral herbs.

Lechowicz (1984) suggested that timing of leaf emergence can only be understood as part of an integrated system of traits directly involved with leaf function and ultimately tied to reproductive fitness. Our objectives were to measure the leaf phenology, recruitment patterns, and photosynthetic characteristics of Ohio buckeye and sugar maple in two upland forest stands in central Illinois. We hypothesized that Ohio buckeye exhibits phenological and photosynthetic patterns indicative of shade avoidance, similar to that of spring ephemeral herbs, in contrast to the more direct shade-tolerance of maple foliage indicated by leaf survival, retention, and relatively higher photosynthetic activity in a forest understory.

STUDY AREAS

This study was performed on two mesophytic upland hardwood stands in east central Illinois. Both Brownfield and Trelease Woods are small remnants of a pre-settlement forested area known as the "Big Grove", which occupied an area of about 10 sq miles NE of Urbana, Illinois (Miceli et al, 1977). Isolated woodlands such as these were known as "prairie groves" and were believed to be separated by fire from the main forests, which were usually found along water courses or on rough morainal land (Boggess, 1964).

Brownfield Woods was leased by the University of Illinois in 1935, and purchased in 1939. Prior to 1935 this 24-hectare woodland had been grazed by cattle, used as a recreational area, partially cut, and also vandalized. After it was acquired by the University it became a natural area and was protected and maintained for research and educational purposes (Edgington, 1991).

Brownfield Woods is located NE of Urbana, Illinois, in the SE 1/4 of Section 34, R9E, T20N, Champaign County, Illinois. Topography is rolling upland with a maximum relief of about 9 meters. A small intermittent stream runs from the northwest corner to the southeast corner. Soils are developed in shallow loess over loam glacial till, and surface drainage is good throughout most of the woodland (Alexander et al, 1974).

Trelease Woods is a 24-hectare woodland purchased by the University of Illinois in 1917, with a history similar to that of Brownfield Woods. Trelease Woods is located NE of Urbana, Illinois, in the SW 1/4 of Section 1, R9E, T19N, Champaign County, Illinois. Topography is flat, with a maximum relief of less than 5 meters. Soils are Mollisols and Alfisols developed in shallow loess over glacial till (Pelz and Rolfe, 1977).

METHODS

Phenological Study

At both Brownfield and Trelease Woods, 5 trees each of sugar maple and Ohio buckeye were randomly chosen for the phenological study. The trees were all approximately 2-3 meters in height. Five branches on each tree were marked with paint, and one leaf was marked with tape on each of those branches. Date of bud break was noted. When leaves began to expand, the length and width (at the widest point) of the marked leaf on each branch was measured. Actual leaf area was determined later by tracing leaves with a planimeter and calculating a linear regression constant (r^2=0.99) by which to estimate leaf area using the length x width measurements as an independent variable. In the case of Ohio buckeye, all 5 leaflets on the marked leaf were measured. For each marked branch, numbers of leaves were counted (number of leaflets for Ohio buckeye). Leaf areas were measured until leaf expansion ceased. Leaf numbers were recorded until leaf abscission. Times of flowering, fruiting, the beginning of senescence (yellowing) and leaf drop were noted. Three open-grown Ohio buckeyes were monitored for budbreak, flowering, and senescence for a general comparison with understory trees.

Measurements of photosynthetically active radiation (PAR, 400-700 nm) were taken throughout the season using a portable quantum sensor (Li-Cor model LI-188B, Lincoln NE). Measurements were made as close to noon as possible on clear days. Light measurements were taken in an open field adjacent to the forest stands, then in the forest. Light intensity was estimated by walking in a straight line for approximately 100 meters with the sensor at approximately 1.2 meters in height. PAR values were integrated over 10 second periods, then averaged.

Photosynthesis measurements of randomly selected understory sugar maple and Ohio buckeye leaves were made under various light intensities and non-limiting temperatures to determine the photosynthetic response of understory trees in situ. Photosynthetic activity was measured with a portable Li-Cor Infrared Gas Analyzer (IRGA, Model LI-6200, Lincoln, NE). A leaf was placed in the chamber, and carbon dioxide changes were monitored for one minute to derive photosynthesis rates. Air temperatures during measurement periods ranged from 20°C in April to 29°C in July.

Inventory

A 30% area inventory of sugar maple and Ohio buckeye trees was taken at both Brownfield and Trelease Woods to determine recruitment of seedlings and saplings into larger size classes. Diameters and frequency of all buckeyes and maples in fifteen-meter-wide strip-transects were measured at midstem with a caliper. The starting positions of non-overlapping, parallel transects were randomly positioned with respect to an edge of the rectangular, 24-ha forest stands. A dbh tape was used for larger trees. These were grouped into size classes. General observations were made concerning gaps in the canopy, tree distribution, density of understory trees, and location of the largest trees.

RESULTS

Phenological Study

In 1991 understory Ohio buckeyes began leaf expansion on March 23, and sugar maples on April 4. In 1992, Ohio buckeyes began leaf expansion on March 3, and sugar maples on April 14. Although Ohio buckeyes began leaf expansion early in 1992, a hard freeze killed many of the new leaflets, and growth did not resume until the end of March. Most of the affected trees were in the southwest corner of Trelease Woods, where trees had begun leaf expansion earlier than in the rest of the forest. Budbreak came approximately 4 days earlier at Trelease Woods than at Brownfield Woods, and buckeyes at Brownfield had just broken bud and were not as severely injured. The open-grown Ohio buckeyes broke bud four to five days later than understory Ohio buckeye trees, and began flowering within a week. Few understory Ohio buckeyes flowered, but those that did were generally found in gaps and along the edges of the forest. Flowering of understory trees began about 1 1/2 weeks after bud break. Large Ohio buckeyes that were dominant or codominant began leafing out on bottom branches first, roughly 3 days after understory trees. Leaves in the upper canopy did not expand for another week. It was noted that the smallest of Ohio buckeyes (<1 meter in height) leafed out first, and the largest (dominant) leafed out last. Since sugar maples began leaf expansion in April, they were not affected by the freeze, except possibly by a delay in bud break. As with Ohio buckeye, maples at Brownfield broke bud about 4 days later than those at Trelease. Sugar maples began flowering within a few days of bud break, but few if any understory maples flowered.

The foliage of understory Ohio buckeyes became spotted with yellow and brown during the last week of May. Trees at Trelease were more discolored than those at Brownfield at the end of May, possibly due to moister foliage associated with the denser understory vegetation at Trelease Woods. Leaf drop began the first week of July and was finished by September 1. Open-grown Ohio buckeyes began senescence near the end of July and were completely devoid of leaves by September 15. Sugar maples began senescence around September 15. Canopy maples turned color and lost leaves at the top of the tree first, and gradually the lower branches lost their leaves. Understory maples did not turn red as the canopy trees did. Sugar maples completed leaf abscission by October 31.

Area measurements of Ohio buckeye leaves began April 1, 1991 and April 2, 1992. Both years had very similar leaf expansion patterns. For 1992 the total area of single leaves of Ohio buckeye from 5 branches on each of 5 trees (n=25) was 75.53 cm^2 at Brownfield and 75.14 at Trelease at the beginning of April. This leaf area sum peaked at Trelease Woods 6 weeks after bud break, with 496 cm^2 total leaf area, and at Brownfield Woods by week 8, with 807.62 cm^2 (Figures 1&2). Although area measurements were greater at Brownfield Woods, the number of leaflets per branch was greater at Trelease Woods. Trees at Trelease had a maximum of 101.12 leaflets per branch, while trees at Brownfield had a maximum number of 82.76 (Figures 3&4). By the first week of August, Trelease buckeyes had 36.68 leaflets per branch, and Brownfield buckeyes had 3.64. Browsing by deer and insects was heavier at Brownfield Woods than at Trelease.

Sugar maple leaf measurements began the third week of April. Leaf area sum peaked at both Brownfield (360.95 cm^2) and Trelease (401.53 cm^2) the second week of May (Figures 1&2). Trelease had a maximum average of 17.92 leaves per branch, and Brownfield maples had 10.28 leaves per branch. Sugar maples at Brownfield Woods were more heavily browsed, and one tree was completely defoliated from browsing by the first week of June, 1992.

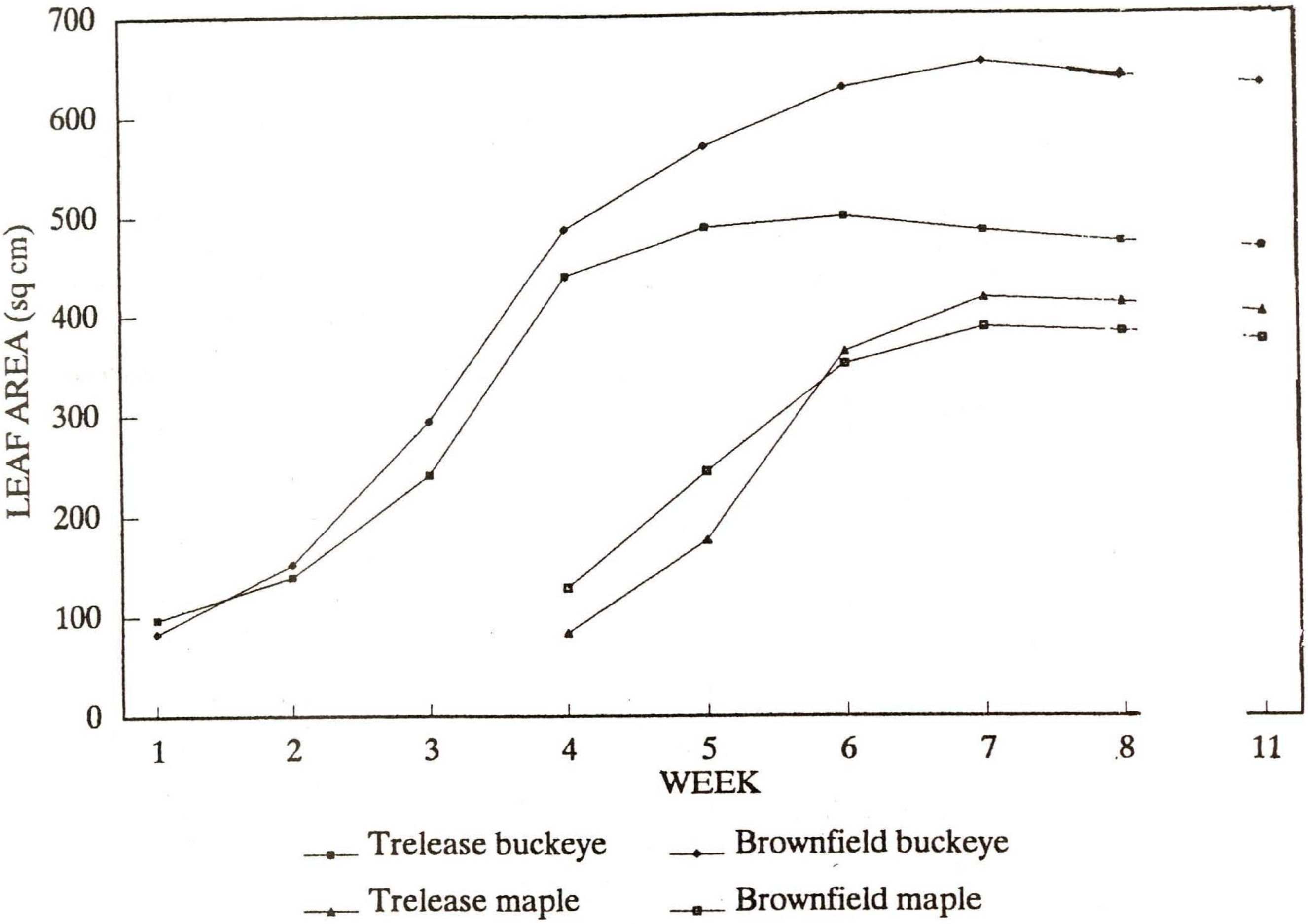


Figure 1.—Leaf area sum for 25 leaves combined of sugar maple or Ohio buckeye at Trelease and Brownfield Woods during 1991. Firest measurement was April 1, last was June 10.

Light and Photosynthesis

Measurements of light intensities in the open and in the forest began the second week of April. Brownfield Woods had slightly higher initial light intensities, with 59% of full sun in the understory, compared with Trelease, which had 47%. By the middle of May, both forest stands had only about 4% incident light reaching the understory. Light intensities in the understory did not begin to increase until the end of October, when most of the canopy maples had lost their leaves (Figure 5).

Photosynthesis measurements for both Ohio buckeye and sugar maple in the understory started approximately 2 1/2 weeks after bud break. Ohio buckeye measurements began the second week in April, and net photosynthesis values ranged from 8.1 umol/m^2/sec CO_2 at 1079 umol/m^2/sec PAR to 16.05 at 1589 umol/m^2/sec PAR for 30 measured leaves. Maple measurements started the

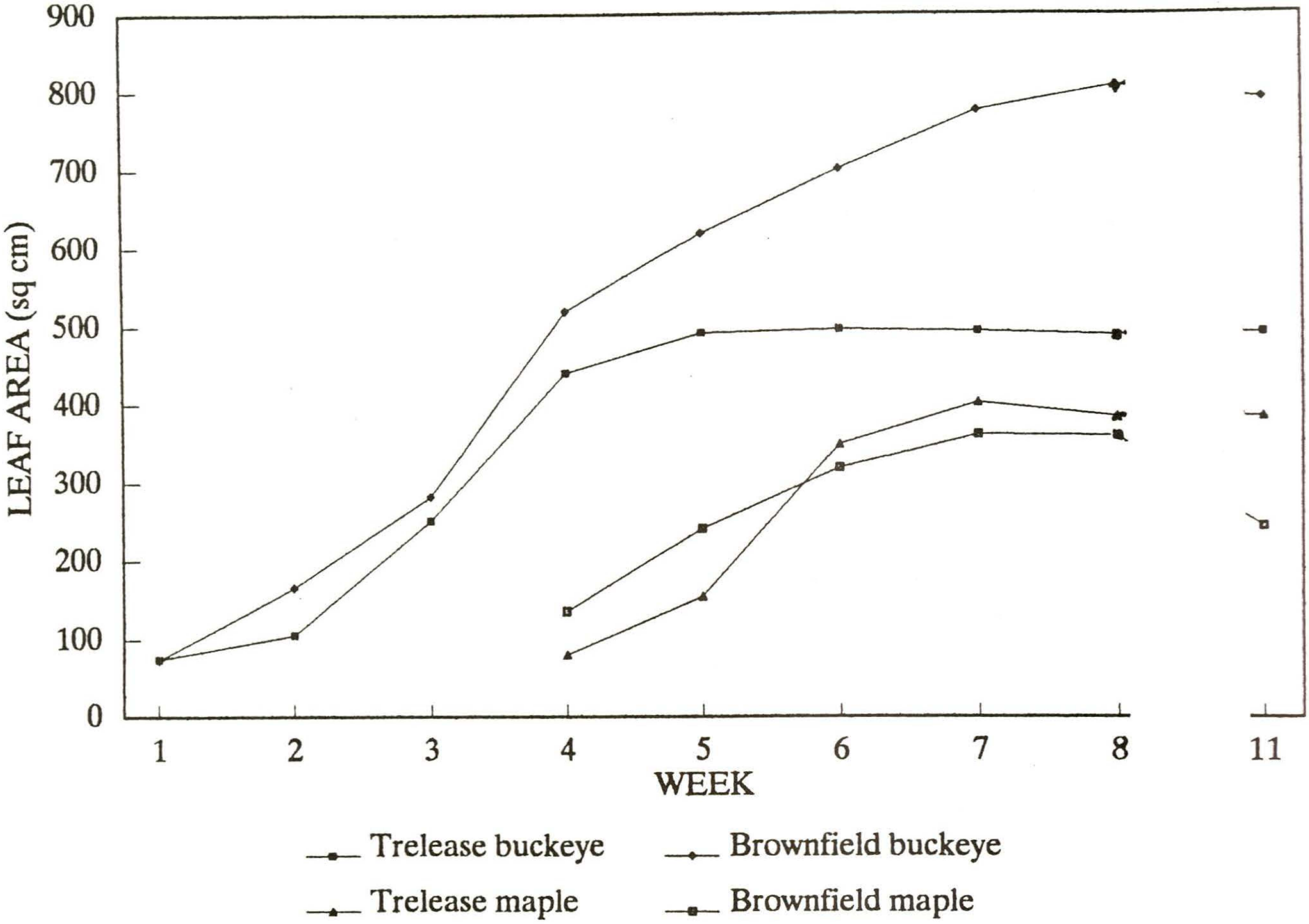


Figure 2.—Leaf area sum for 25 leaves combined of sugar maple or Ohio buckeye at Trelease and Brownfield Woods during 1992. First measurement was April 2, last was June 9.

last week of April, with maximum photosynthesis rates of 10.2 umol/m^2/sec CO_2 at a light intensity of 1269 umol/m^2/sec PAR and a minimum rate of 0.37 umol/m^2/sec CO_2 at a light intensity of 45 umol/m^2/sec PAR for 30 measured leaves. By the second week of June, Ohio buckeye photosynthesis rates had dropped to a range of 0.15 to 7.3 umol/m^2/s CO_2 with light intensities ranging from 32 to 1391 umol/m^2/sec PAR for 20 sampled leaves. In July, Ohio buckeye photosynthetic rates were all less than 1, while maple rates averaged 4-5 umol/m^2/sec CO_2 for 20 sampled leaves per species. All July light intensities were between 30 and 50 umol/m^2/sec PAR.

Diameter Class Distribution

At Brownfield Woods a total of 9,146 Ohio buckeye and 25,748 sugar maple trees were measured, resulting in an average of 1,242 and 3,496 trees/hectare, respectively. The largest percentage of stems for both species was in the 0 to 1-cm stem diameter class, Ohio buckeye having 721 and sugar maple having 2,418 stems/ha. Ohio buckeye stem density dropped sharply between the 2-4 and 4-6 cm classes, with 37 stems/ha in the 4-6 cm class and 133 stems/ha in the 2-4 cm diameter class. Sugar maple stems decreased from 338 stems/ha in the 2-4 cm class to 109 stems/ha

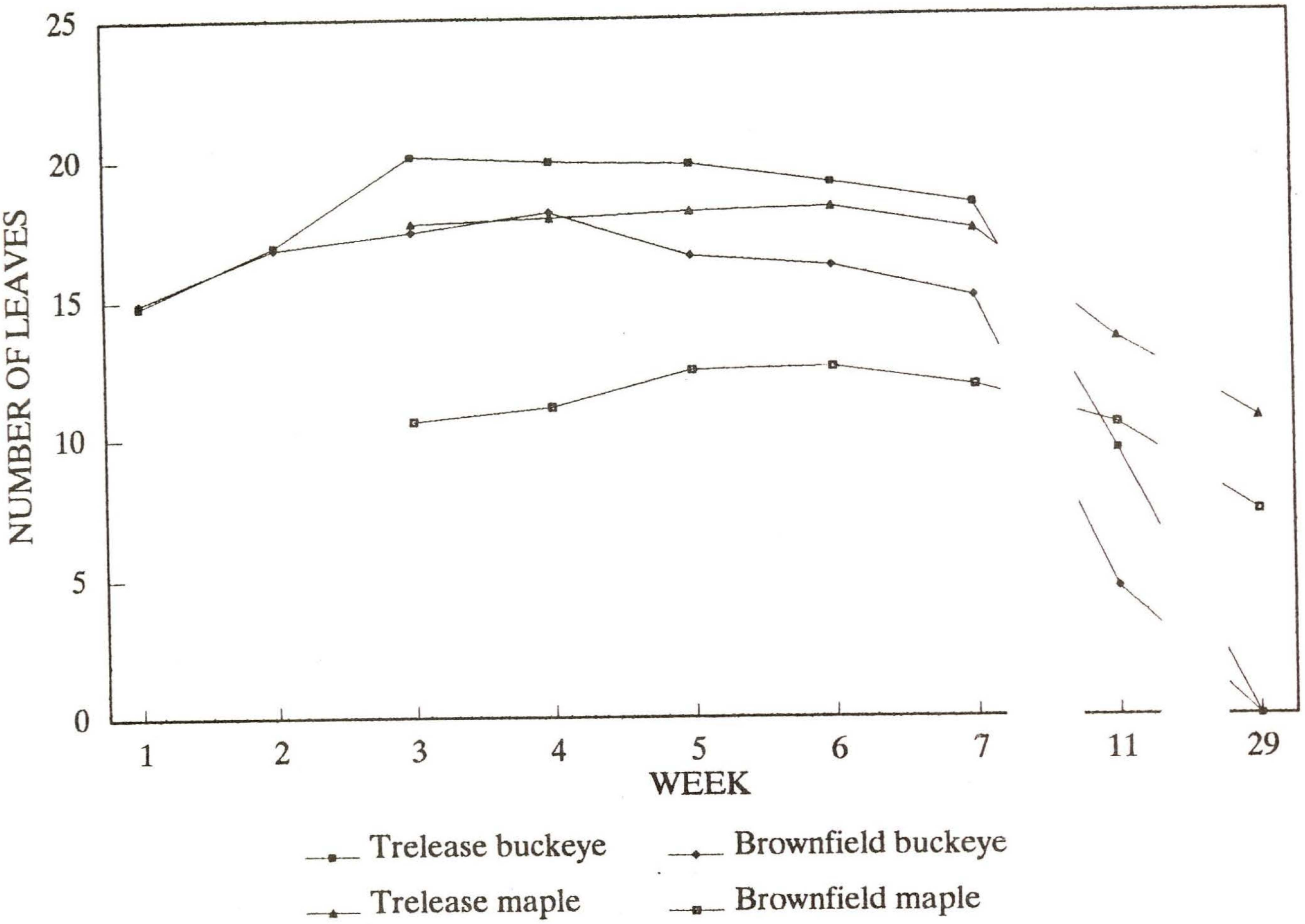


Figure 3.—Number of leaves per branch (n=25) for Ohio buckeye and sugar maple at Trelease and Browfield Woods during 1991. First measurement was April 8, last was October 23.

in the 4-6 cm class. Ohio buckeye had 1.2 trees/ha 30 cm and larger, while sugar maple had 45.5. Figure 6 shows the distribution of size classes of Ohio buckeye and sugar maple at Brownfield Woods.

At Trelease Woods 16,723 sugar maples and 9,397 Ohio buckeyes were measured. As at Brownfield, the majority of the stems measured were in the 0-1 cm class, Ohio buckeye having 626 stems/ha and sugar maple having 979 stems/ha. In contrast to the situation at Brownfield, the greatest decrease in Ohio buckeye stem density came at the 2-4 cm class. There were 406 stems/ha 1-2 cm in diameter and 88 stems/ha in the 2-4 cm class. Trelease Woods also had a greater number of large Ohio buckeye trees than Brownfield Woods, with 4.8 stems/ha that were 30+ cm. Sugar maple stems decreased from 372 stems/ha in the 2-4 cm class to 176 stems/ha in the 4-6 cm class. There were 18.9 maple stems/ha in the 30+ cm class. Figure 7 shows the size class distribution of sugar maple and Ohio buckeye at Trelease Woods.

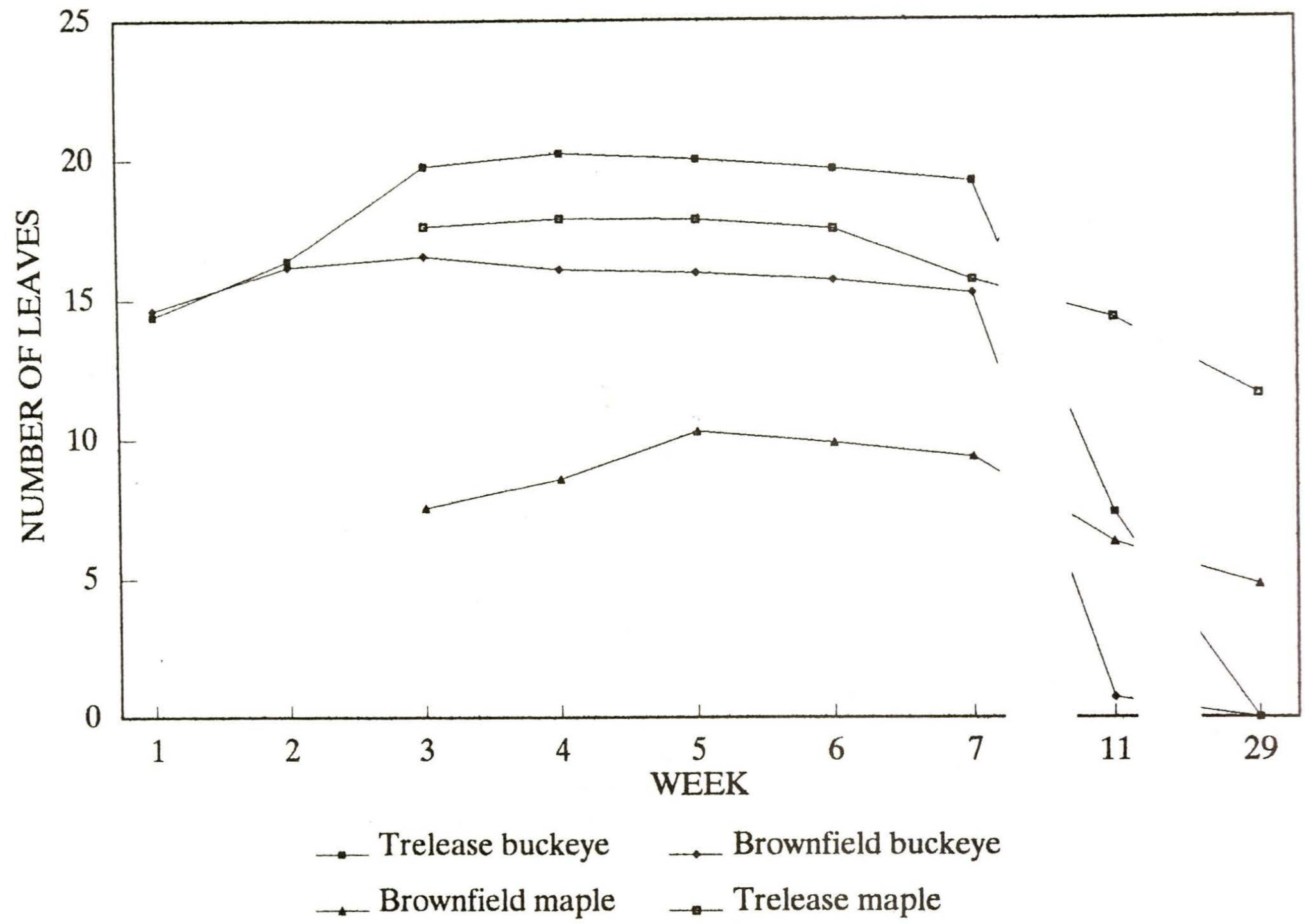


Figure 4.—Number of leaves per branch (n=25) for Ohio buckeye and sugar maple at Trelease and Brownfield Woods during 1992. First measurement was April 7, last was October 21.

DISCUSSION

At both Trelease and Brownfield Woods, the majority of Ohio buckeyes were found in gaps and along the edges of the forest. The larger trees were almost always clustered together in groups of two or three. Trelease Woods had more gaps and a less closed canopy than did Brownfield, which could explain why there were more large Ohio buckeyes at Trelease. The northeastern corner of Trelease Woods has an open canopy with few large dominant trees. Many small to medium diameter (6-30 cm) buckeyes were found in this area. Most of these trees also flowered in the spring, while others under a more-closed canopy did not. Sugar maples were not concentrated in gaps and had a more even distribution throughout the forest, as is common for shade tolerant species. There were a large number of sugar maple seedlings and they were also the dominant canopy species in both forest stands, having a high percentage of seedling recruitment into larger size classes. Large numbers of Ohio buckeye seedlings, but few canopy size trees, suggest that Ohio buckeye does not survive as well as sugar maple under closed canopy conditions.

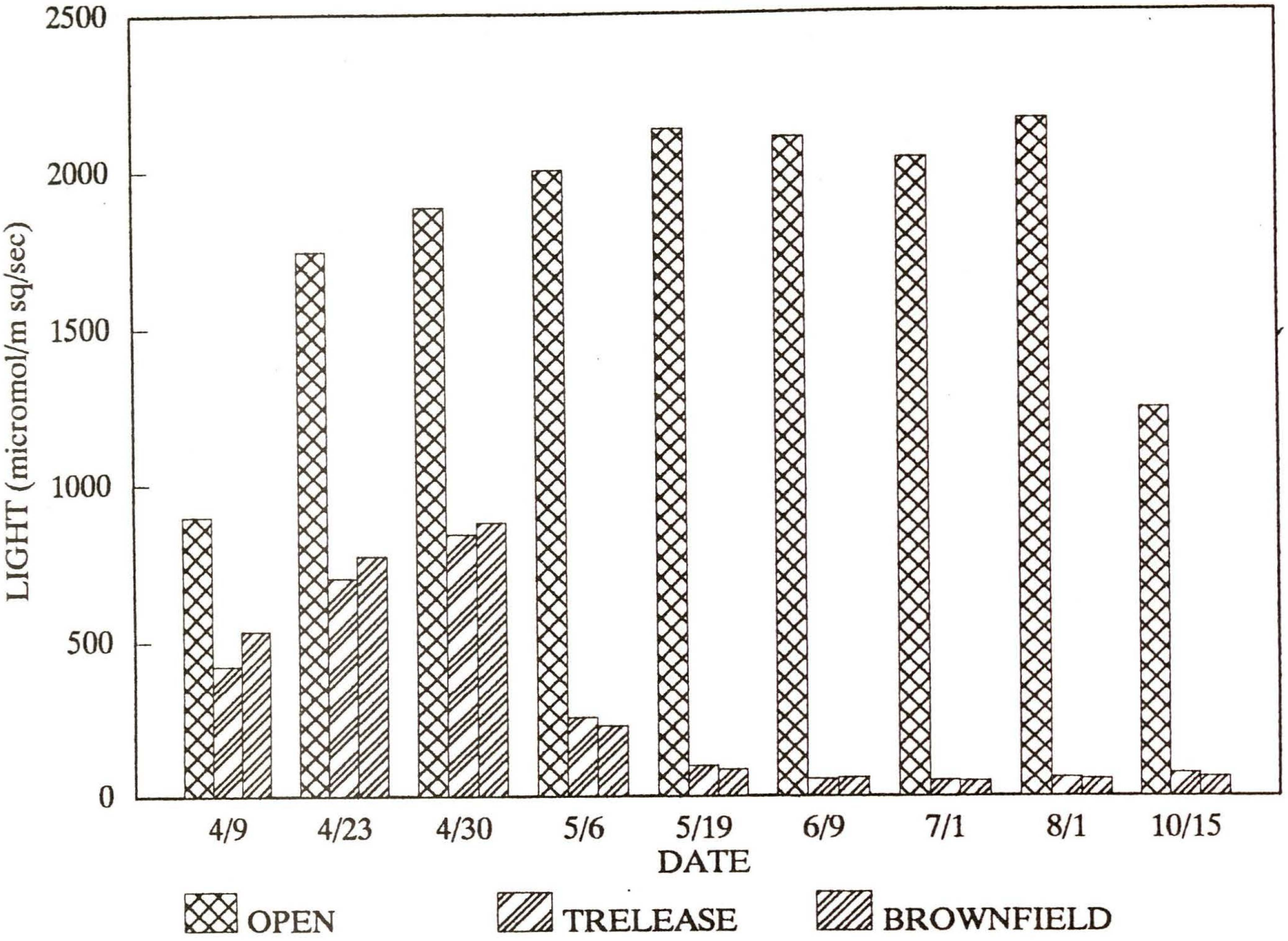


Figure 5.—Open vs. forest understory light intensities for 1992.

During both years of this study, Ohio buckeye was the first tree species to leaf out, concurrently with the prevernal spring wildflowers. Ohio buckeye was also the first tree species to exhibit leaf color fading, soon after canopy closure, and to shed its leaves, beginning in July. Other understory tree species had not begun senescence until the first of September. In early spring, before canopy closure, Ohio buckeye photosynthesis rates were relatively high in comparison with sugar maple, and when the canopy closed, the Ohio buckeye rates dropped to a lower relative level. Ohio buckeye trees grown in the open showed the same early leafing and senescence trends as did those in the understory, but with slight differences. Open grown trees had much larger buds that took longer to open and were much softer than those of understory trees. Flowering occurred more quickly and profusely in open grown trees, and senescence was later in occurrence. Leaves were not completely shed until September 15, while understory trees were bare by September 1.

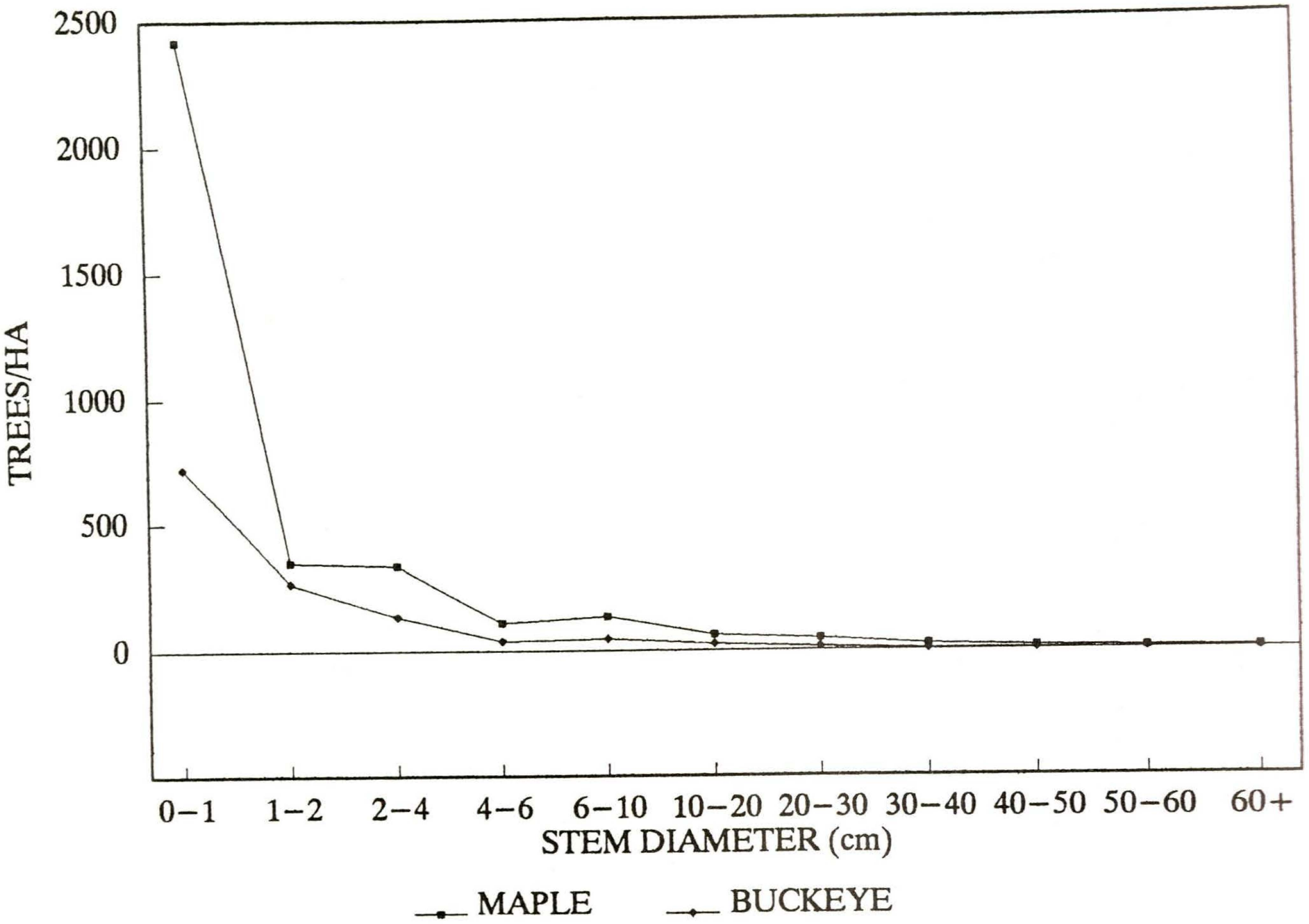


Figure 6.—Distribution of sugar maple and Ohio buckeye by stem diameter at Brownfield Woods for 1992.

These characteristics of Ohio buckeye trees suggest that they have adapted to understory conditions and compensate for low light levels in the summer by early leafing, thereby avoiding shade. This is in contrast to sugar maples, which can tolerate low light levels in the understory for extended periods of time while maintaining low levels of photosynthesis (4-5 umol/m^2/s). Greater maple photosynthetic efficiency at understory light intensities provides a more positive carbon balance longer than for Ohio buckeye, thus affording an advantage to longer maple leaf retention. We observed Ohio buckeye trees in the open to retain foliage until mid September, 4 to 6 weeks longer than leaf retention by Ohio buckeye trees in the forest understory. Thus, Ohio buckeye seem to have a genetic tendency to senesce and drop foliage earlier than other local deciduous tree species, which retain foliage until late October. This genetic tendency to drop foliage early seems to be intensified in forest understories. The ecological consequence of these differences in tree physiology might include less recruitment of Ohio buckeye into larger diameter classes at low light intensities in comparison with maple, increased flowering and regeneration of Ohio buckeye in gaps and openings, and increased competitive ability of Ohio buckeye in gaps and openings. Sugar maples were more abundant and uniformly distributed in the forest stands than Ohio buckeye trees, which flourished in gaps, open stands, and near sunny edges.

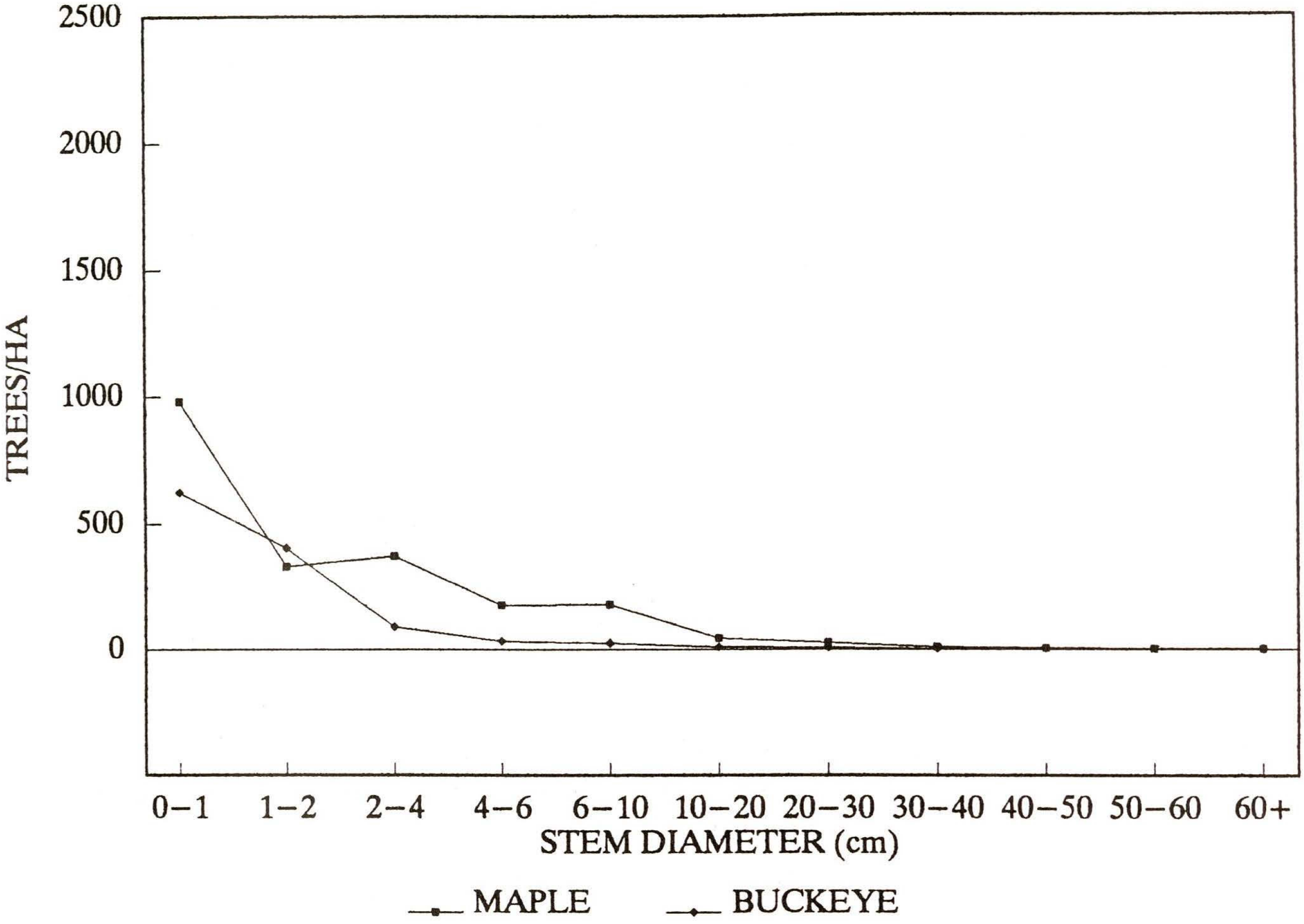


Figure 7.—Distribution of sugar maple and Ohio buckeye by stem diameter at Trelease Woods for 1992.

LITERATURE CITED

Alexander, J.D., J.B. Fehrenbacher, and D.C. Hallbick. 1974. Soil Survey: Champaign-Urbana area, Illinois. Univ. Ill. Agric. Exp. Sta. Soil Rep. 100. 130 p.

Boggess, W.R. and L.W. Bailey. 1964. Brownfield Woods, Illinois: Woody vegetation and changes since 1925. Am. Mid. Nat. 71: 392-401.

DePamphilis, C.W. and H.S. Neufeld. 1989. Phenology and ecophysiology of *Aesculus sylvatica*, a vernal understory tree. Can. J. Bot. 67: 2161-2167.

Edgington, J.M. 1991. Brownfield Woods, Illinois: Present composition and changes in community structure. Transactions, Ill. State Acad. Sci. 84: 95-112.

Fowells, H.A. 1965. Silvics of forest trees of the U.S. USDA Agriculture Handbook 271 pp. 66-77.

Hett, J.M. and O.L. Loucks. 1971. Sugar maple (*Acer saccharum* Marsh.) seedling mortality. J. Ecol. 59: 507-520.

Lechowicz, M.J. 1984. Why do temperate deciduous trees leaf out at different times? Adaptation and ecology of forest communities. Am. Nat. 124: 821-842.

Miceli, J.C., G.L. Rolfe, D.R. Pelz, and J.M. Edgington. 1977. Brownfield Woods, Illinois: Woody vegetation and changes since 1960. Am. Mid. Nat. 98: 469-476.

Pelz, D.R. and G.L. Rolfe. 1977. Stand structure and composition of a natural mixed hardwood forest. Transactions, Ill. State Acad. Sci. 69: 446-453.

Impacts of Pear Thrips on a Pennsylvania Sugarbush: Third Year Results

Thomas E. Kolb[1] and Larry H. McCormick[2]

Abstract: Pear thrips, *Taeniothrips inconsequens* (Uzel) (Thysanoptera: Thripidae), were first positively identified as causing damage to sugar maple (*Acer saccharum* Marsh.) in forest environments in the United States in 1980. Damage in Pennsylvania from this insect has occurred consistently since 1980, with the most extensive impact in 1988 (0.5 millon ha). Sap characteristics and crown condition were monitored for three years following a 1989 thrips attack in a Pennsylvania sugarbush on 56 trees representing a range of thrips damage. Heavy damage in 1989 was associated with increased crown transparency for two summers following the attack. Calculated syrup production was greatest in all years for trees with light damage and lowest for trees with heavy damage. Reduced syrup production in trees with heavy damage resulted from lower sap volume in all years and lower sap sugar concentration in 1990 and 1992 compared to trees with light damage. The results indicate that pear thrips damage in 1989 had a detrimental impact on sugar maple health and syrup production for three years following the attack.

INTRODUCTION

Until recently, the pear thrips, *Taeniothrips inconsequens* (Uzel) (Thysanoptera: Thripidae), was considered primarily an insect pest of fruit trees (Foster and Jones 1915, Bailey 1944). Pear thrips were first positively identified as causing damage to sugar maple (*Acer saccharum* Marsh.) in forest environments in the northeastern United States in 1980 (Laudermilch 1988). In the 1980's, heavy damage to sugar maple occurred for several years in the Northeast, with the greatest impacts in 1988 and 1989 (Parker 1991). Damage in Pennsylvania from this insect has occurred consistently since 1980, with the most extensive impact in 1988 (0.5 millon ha). Symptoms of pear thrips damage to sugar maple include undersized leaves that are tattered and chlorotic, resulting in an unusually thin crown (Houston et al. 1990, Kolb and Teulon 1991).

Adult pear thrips emerge from the soil in early spring and feed on foliar and flower tissues, often in swollen buds prior to budburst (Bailey 1944, Skinner et al. 1991). Adults oviposit on succulent plant tissues, where larvae develop. Both adult and larval thrips feed by puncturing epidermal and mesophyll cells with a lance-like mandible, followed by insertion of tube-like stylets into which the contents of ruptured cells are drawn (Heming 1978, Chisholm and Lewis 1984, Hunter and Ullman 1989). Factors that promote pear thrips damage to sugar maple leaf area include synchrony between budburst and insect emergence from the soil, and cool temperatures that slow budburst and lengthen the duration of feeding prior to leaf expansion (Kolb and Teulon 1991, Kolb and Teulon 1992).

---

[1] Assistant Professor, School of Forestry, Northern Arizona University, Flagstaff, AZ 86011.

[2] Associate Professor, School of Forest Resources, The Pennsylvania State University, University Park, PA 16802.

Impacts of pear thrips to sugar maple have been addressed in only a few studies. In a greenhouse study, seedlings with heavy pear thrips damage had greater photosynthetic rates under conditions of high light intensity and high soil moisture, but slightly lower rates under conditions of low soil moisture compared with undamaged seedlings (Kolb et al. 1991). Lower root carbohydrate concentrations the fall following attack have been reported for sugar maple trees damaged by pear thrips compared with undamaged trees in studies in Massachusetts (Smith et al. 1991) and Pennsylvania (Kolb et al. 1992). Sugar maples that refoliate following heavy pear thrips damage often have greater fall root carbohydrate concentrations than damaged trees that do not refoliate (Smith et al. 1991, Burns 1991), indicating that refoliation accelerates recovery. While these studies have addressed relatively short-term physiological impacts of thrips damage on sugar maple, longer term effects of thrips damage on sugar maple health and syrup production are poorly understood.

We have measured sap sugar concentrations, sap volumes, and crown conditions of 56 sugar maple trees in a Pennsylvania sugarbush for three years following a pear thrips attack in 1989. Trees in the sugarbush exhibited different degrees of damage, allowing assessment of the impact of damage on trees growing on the same site with similar management history. Results of the first two years of the study were described in Kolb et al. (1992). This paper presents data from the third year of the study and compares temporal variation in sap and crown characteristics over three years following the 1989 attack. In addition, we have studied variation in budburst phenology among these trees to gain insight into how differences in damage severity within the sugarbush occur.

METHODS AND MATERIALS

Stand Condition

The study site is an uneven-aged northern hardwood stand in Somerset Co., Pennsylvania. Aspect is northeast, and elevation is 720 m. Soil in the stand is classified as a Rayne-Gilpin silt loam. Sugar maple has been favored in the stand by periodic cuttings of larger stems of other species. Consequently, almost all dominant or co-dominant trees in the stand are sugar maples approximately 30 m in height. Understory trees include sugar maple, black cherry (*Prunus serotina* L.), red maple (*Acer rubrum* L.), black birch (*Betula lenta* L.), and beech (*Fagus grandifolia* L.). Stand basal area in 1991 averaged 19.7 m^2/ha. Trees in the stand have been tapped yearly for maple syrup production for at least the last 50 years.

Pear Thrips Damage

Light pear thrips damage was first noticed in the stand in 1988. In 1989, counts of adult thrips on branch samples from the middle or upper crown of 10 randomly selected co-dominant sugar maples in the stand averaged 13 per bud on April 28 and 7 per bud on May 12. Previous studies where pear thrips were confined on sugar maple buds and seedlings indicated that five adult thrips per bud is enough to cause foliar damage consisting of a reduction in leaf size, chlorosis, tattered leaf margins, and leaf cupping (Kolb and Teulon 1991, Kolb and Teulon 1992, E. E. Simons - PA Bureau of Forestry - unpublished data). By late-May, many trees in the stand exhibited these foliar symptoms of thrips damage. In some cases, heavily damaged leaves dropped from the crown soon after budburst. Damage could not be explained by weather events such as late frost, and no other biological agents were observed that could have caused this type of damage.

Damage varied widely among sugar maples in the stand, with no apparent relationship between damage severity and location within the stand. In late-June 1989, degree of damage to 56 trees in the stand was evaluated from the ground by two observers using five classes:

very light - <10% of foliage damaged
light - 10% to 30% of foliage damaged
moderate - 30% to 60% of foliage damaged
heavy - 60% to 90% of foliage damaged
very heavy - >90% of foliage damaged

Number of trees in each damage class were: very light - 12, light - 9, moderate - 12, heavy - 18, and very heavy - 5. Diameter at breast height (DBH) of trees in each damage class averaged between 41 and 46 cm (individual tree range 22 to 77 cm), except in the very heavy class which averaged 56 cm (range 30 to 98 cm). Trees in the heavy and very heavy damage classes produced few new leaves (refoliation) in 1989 following damage.

Stresses experienced by all study trees in the stand since the 1989 thrips attack include summer drought in 1991, and heavy flowering in 1992. Pear thrips were present in the stand in 1990 and 1991, but damage was very light to light on all trees. Thrips damage in the stand in 1992 was heavier than in 1990 and 1991, and damage varied widely among trees as in 1989. No other substantial insect damage occurred in the stand from 1989-1992.

Crown Condition

Two measures of crown condition (transparency, dieback) were scored on all study trees in early June 1990-92. Crown transparency is the percentage of full sun light penetrating the crown. Dieback is the proportion of crown volume containing dead branches with tips less than 2.5 cm in diameter (see Bauce and Allen 1991). Both measures were visually scored from the ground by two observers using a 12 percentage class system developed for the North American Sugar Maple Decline Project (Millers et al. 1991). Differences in crown dieback and transparency among classes were analyzed by the Kruskal-Wallis nonparametric test.

Budburst Phenology

Budburst phenology was measured in 1991 and 1992 on all trees every one or two days between early April and mid-May. On each tree, the Julian date that leaf blades were fully visible from the ground with binoculars was recorded for both middle and upper crown positions. Dates were subjected to analysis of variance with 1989 damage class, crown position (middle or upper), and their interaction as factors.

Number of pear thrips oviposition sites, a measure of insect activity, was measured in 1991 and 1992 on leaves sampled from both the middle and upper positions of the crown from the five trees with earliest budburst and the five trees with latest budburst in each year. Samples were collected in early June by removing one or two twigs from each crown position with shotgun blasts. Number of oviposition sites on the underside of the petiole and three major veins was counted (7.5X magnification) on a random sample of five leaves from each crown position. Crown position means from each tree were subjected to analysis of variance with budburst class (early or late), crown position (middle or upper), and their interaction as factors.

Sap Characteristics

Sap sugar concentration and volume were measured on all study trees every one to five days (depending on sap flow conditions) during the traditional sap collection season in 1990-92. In late-February of each year, each tree was tapped twice using commercial taps (inside diameter 11 mm). Sap from both taps on a tree drained into a covered plastic bucket (18 liter capacity). Measurements were made on 9 days between March 10 and April 2 in 1990, 28 days between February 24 and April 1 in 1991, and 22 days between February 21 and April 6 in 1992. On each sample day, volume of sap in each bucket was measured in the late-afternoon or evening after the daily sap flow had ceased using a graduated cylinder. The sugar concentration of a representative 25 ml sample from each tree was measured in the laboratory within two hours of collection using a temperature compensating refractometer (Reichert-Jung Mark II, Cambridge Instruments, Buffalo, NY).

Sap volume and sugar concentration for each collection in each year were compared among 1989 damage classes by analysis of variance with DBH as a covariate to remove variation associated with tree size. Total syrup production in each year was calculated for each damage class. In each year, average sugar concentration over all days in each class (adjusted to the same DBH) was used to determine the amount of sap needed to produce a liter of syrup by the "rule of 86" formula, which states that 86 divided by sap sugar concentration equals the number of liters of sap required for one liter of syrup (see Walters 1982). For each class, this quantity was divided into the average seasonal volume collection to calculate yearly syrup production.

RESULTS

Crown Condition

Crown transparency differed significantly among 1989 damage classes for two summers following the 1989 thrips attack (p=0.03 in 1990, p=0.09 in 1991). In both years, average transparency was greater in the very heavy and heavy damage classes compared with the very light, light, and moderate classes (Figure 1). Transparency in all classes decreased from 1990 to 1991, indicating an improvement in crown condition. Changes in transparency from 1991 to 1992 were variable for 1989 damage classes. Transparency increased during this period in the very light, light, and moderate classes and decreased in the heavy and very heavy classes. Transparency in 1992 was greatest in the moderate and light classes compared to other classes, but these differences were not significant (p=0.18). Leaves from trees whose transparency increased from 1991 to 1992 were dwarfed, tattered, and chlorotic in 1992 while those from trees whose transparency was constant or decreased were only lightly chlorotic and near normal in size. This suggests that differences in transparency in 1992 resulted from differences in the severity of pear thrips damage.

Crown dieback in all years did not exceed 11% in any class and differences among 1989 damage classes were not significant (p=0.5, 0.7, 0.9 for 1990, 1991, and 1992, respectively). In both 1990 and 1991, there was a trend of greater dieback with heavier 1989 damage which did not occur in 1992 (Figure 2). Small decreases in dieback occurred in all damage classes from 1990 to 1991, while changes from 1991 to 1992 were variable among classes (Figure 2).

Budburst Phenology

Budburst averaged over all classes in 1991 occurred two days earlier in the middle compared with the upper crown (p=0.04). In contrast, differences in budburst between crown positions in 1992 were less than one day and not significant (p=0.36). Budburst date differed among 1989 damage

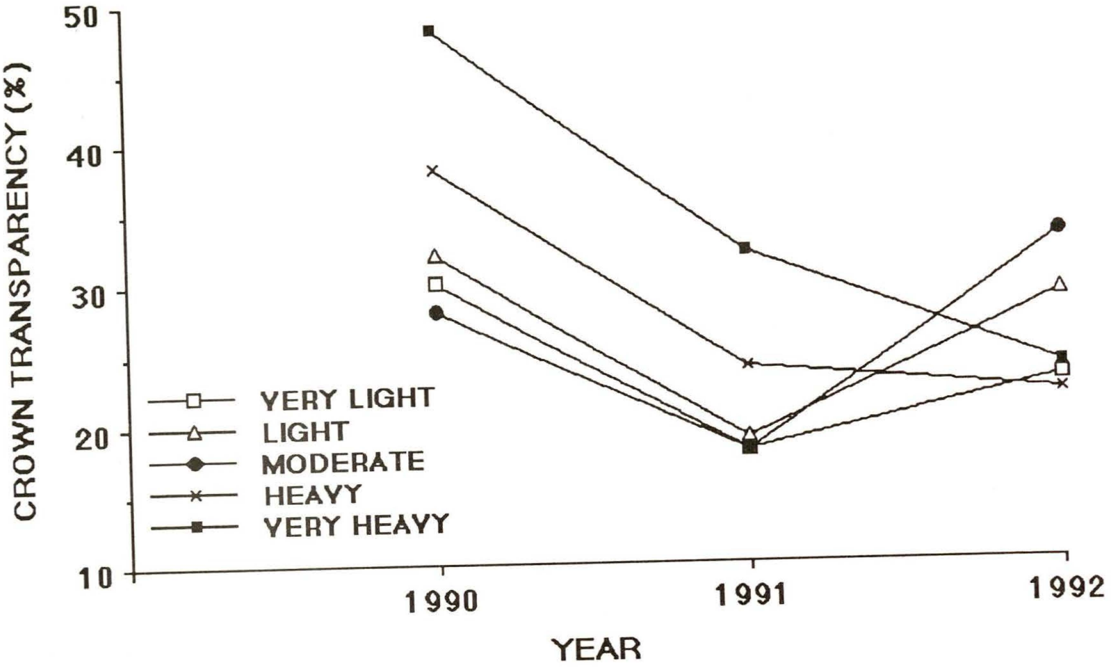


Figure 1.—Crown transparency of sugar maples from five 1989 pear thrips damage classes in June 1990, 1991, and 1992. Each value is the average of 5 to 18 trees.

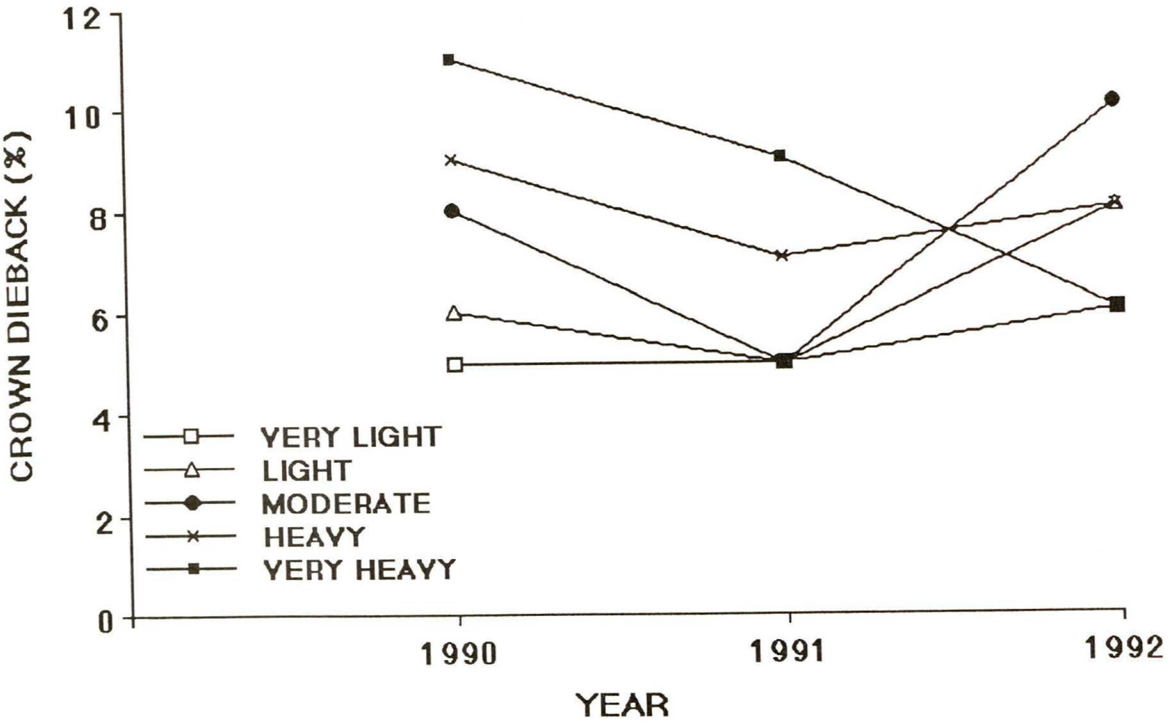


Figure 2.—Crown dieback of sugar maples from five 1989 pear thrips damage classes in June 1990, 1991, and 1992. Each value is the average of 5 to 18 trees.

classes in both years (p=0.0001 in 1991, p=0.03 in 1992), and differences were consistent over crown positions (p=0.97, 0.98 for the class x crown position interaction in 1991 and 1992, respectively). In both years, trees in the very heavy class had the earliest average budburst date (May 2 and 4 for 1991 and 1992, respectively), followed by the heavy (May 4 and 5 for 1991 and 1992, respectively), moderate (May 6 and 6 for 1991 and 1992, respectively), light (May 9 and 7 for 1991 and 1992, respectively) and very light classes (May 9 and 7 for 1991 and 1992, respectively). Individual tree budburst dates in 1991 were positively (r=0.56) and significantly (p<0.01) correlated with dates in 1992.

Number of pear thrips oviposition sites per leaf averaged over all classes in 1991 did not differ (p=0.34) between middle (mean=1.8) and upper crown positions (mean=1.1) and there was no interaction between crown positions and budburst dates (p=0.83). The five trees with earliest phenology in 1991 broke bud between April 26-30 and had more (p=0.07) oviposition sites per leaf (mean=21.0) than the five trees with latest phenology (mean=7.9) which broke bud between May 12-14. Significant sources of variation in number of pear thrips oviposition sites per leaf differed between 1991 and 1992. In contrast to 1991, greater numbers of oviposition sites in 1992 occurred in the upper (mean=3.4) compared with the middle crown (mean=1.7) (p=0.008), and these differences were consistent over budburst dates (p=0.48 for budburst date x crown position interaction). The five trees with earliest phenology in 1992 broke bud between May 4-6 and had about the same number of oviposition sites (mean=2.7) as the five trees with latest phenology (mean=2.4) which broke bud between May 11-14 (p=0.59).

Sap Characteristics

Total per tree sap volume was considerably lower in 1990 than in 1991 and 1992 (Figure 3). Total per tree sap volume in all years was greatest in the very light 1989 damage class, intermediate in the light, moderate, and heavy classes, and lowest in the very heavy class. These differences were significant (p<0.10) on 13 collection dates in 1991 and 6 dates in 1992, but no significant differences occurred in 1990.

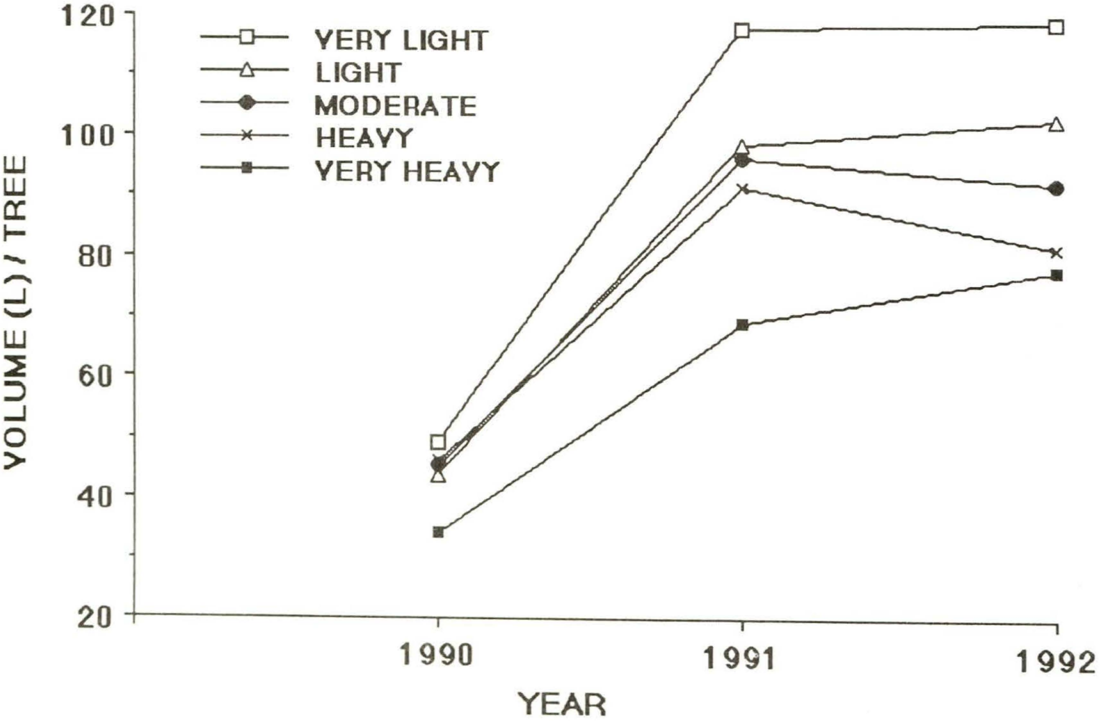


Figure 3.—Total per tree sap volume of sugar maples from five 1989 pear thrips damage classes for the 1990, 1991, and 1992 sap seasons. Values in each year are averages over dates and trees (n = 5-18 trees per class).

Sap sugar concentration averaged over all collection dates increased from 1990 to 1992 (Figure 4). There were small (0.1 to 0.3%) but significant (p≤0.10) differences in sap sugar concentration among damage classes on two collection dates in 1990, four dates in 1991, and three dates in 1992. In 1990, sap sugar concentration was consistently greater in the very light class compared with heavier degrees of damage. In contrast, sap sugar concentration in 1991 was consistently greater in the very heavy class compared with other classes. In 1992, sap sugar concentration on most collection dates was greatest in the very light and light classes compared with the moderate, heavy, and very heavy classes.

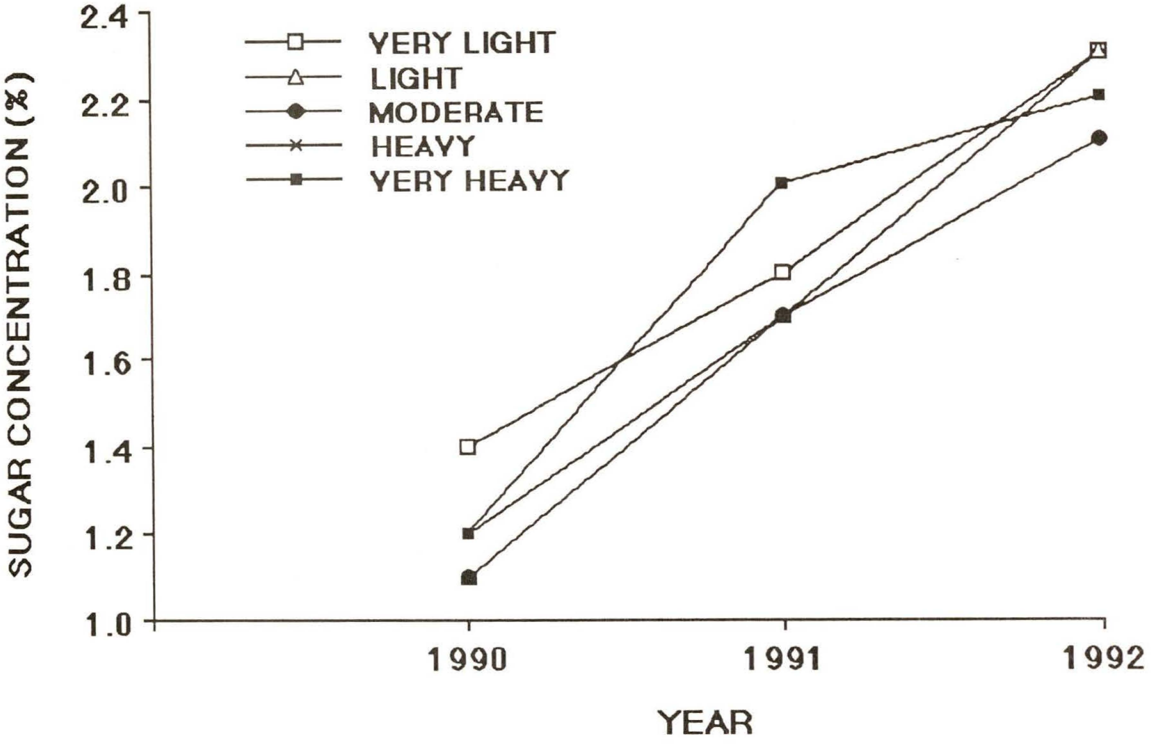


Figure 4.—Sap sugar concentration of sugar maples from five 1989 pear thrips damage classes for the 1990, 1991, and 1992 sap seasons. Values in each year are averages over dates and trees (n = 5-18 trees per class).

Total per tree syrup production increased from 1990 to 1992 (Figure 5). Syrup production in all years was greatest in the very light class, intermediate in the light and moderate classes, and lowest in the heavy and very heavy classes. Compared with the very light class, light damage reduced total syrup production by 26% in 1990, 19% in 1991, and 16% in 1992; moderate damage reduced total syrup production by 23% in 1990, 24% in 1991, and 30% in 1992; heavy damage reduced total syrup production by 19% in 1990, 28% in 1991, and 39% in 1992; and very heavy damage reduced total syrup production by 40% in 1990, 35% in 1991, and 39% in 1992.

DISCUSSION

Our analysis of pear thrips impact in this study assumes similar background stresses on trees in different damage classes prior to the 1989 pear thrips attack. Unfortunately, we do not have data on sap production or crown condition of these trees prior to 1989. Further, we cannot rule out the involvement of other pathogenic agents associated with thrips damage in causing differences in

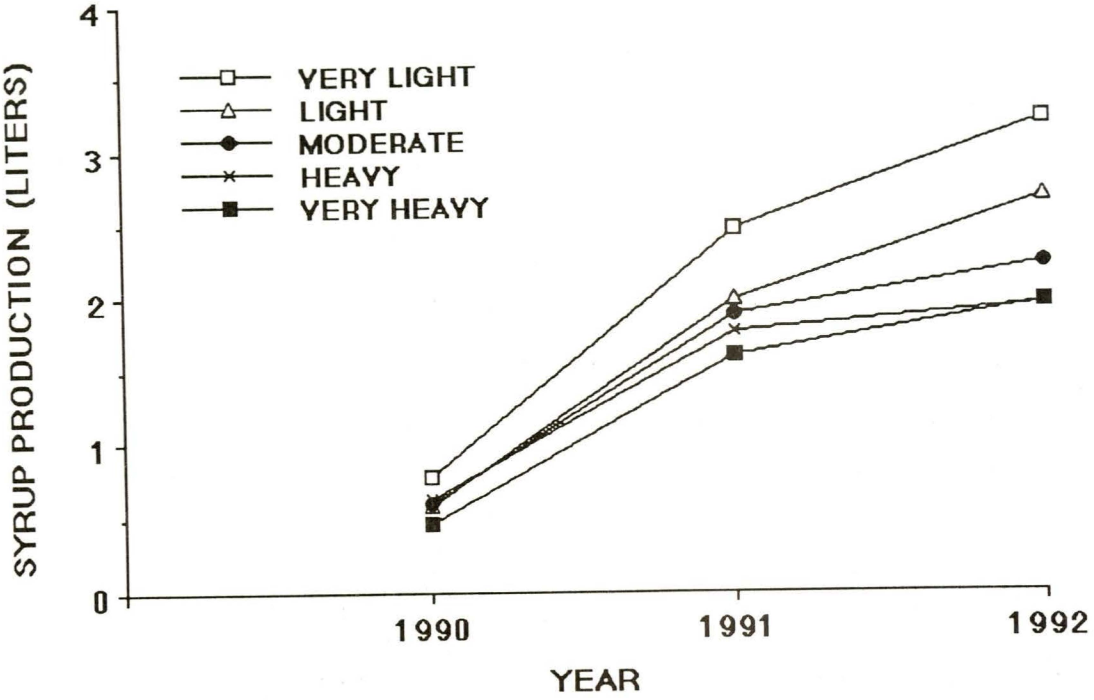


Figure 5.—Tatoal per tree syrup production of sugar maples from five 1989 pear thrips damage classes for the 1990, 1991, and 1992 sap seasons. Values in each year are averages over dates and trees (n = 5-18 trees per class).

syrup production and crown condition. For example, sugar maple leaves damaged by pear thrips can be infected by anthracnose fungi (Nash et al. 1991), which could further damage leaf area and function. Defoliation can also predispose sugar maples to attack by the fungus *Armillaria mellea* (Wargo 1972). With these caveats, our data suggests that heavy pear thrips damage in 1989 reduced maple syrup production in this sugarbush over the next three years following attack.

Sap volume and sugar concentration in the three years following the 1989 thrips attack were generally greater for trees with light damage compared to trees with heavy damage. Trees in the very heavy damage class were the only exception to this trend, where sap sugar concentration in 1991 was greatest of all classes. Elevated sap sugar concentrations have been previously reported for heavily defoliated or declining sugar maples (Gregory and Wargo 1986, Herrick 1988, Allen et al. in press). Elevated sap sugar concentration may represent a physiological response to defoliation or dieback, perhaps related to mobilization of carbohydrates associated with refoliation and crown replacement. Lower sap volume and/or sugar concentration in trees with moderate to very heavy thrips damage reduced calculated syrup production by 19-40% in the first season following damage, 24-35% in the second season following damagee, and 30-39% in the third season following damage, with the greatest reductions occurring in the most severely damaged trees.

Sap volume, sugar concentration, and syrup production were considerably lower in 1990 than in 1991 or 1992. Many sugarbush operators we interviewed in Pennsylvania stated that syrup production was lower in 1990 than for any year on record. Poor production in 1990 may have resulted from unusually warm temperatures that occurred between late-February and late-March during sap collection. Record high temperatures were measured throughout Pennsylvania on several dates during this period and hard freezes were uncommon. Periodic thawing of frozen xylem is required to sustain dormant-season sap volume flow from sugar maple stems (Tyree 1983, Johnson et al. 1987), and enzymes that convert starch to sugar in sugar maple xylem are active at temperatures slightly above freezing (Marvin et al. 1971). Warm temperatures also promote the growth of micro-organisms in taps and tubing that can reduce sap sugar concentration and volume. Given the results of this study, it is also likely that heavy thrips damage that occurred in many Pennsylvania sugarbushes in 1988 and 1989 also reduced syrup production in 1990.

Trees with very heavy or heavy thrips damage in 1989 had more transparent crowns and slightly more dieback than trees with less damage for two years (1990-91) following the attack. This indicates detrimental impacts of heavy thrips damage on crown vigor in this sugarbush for two years following the attack. In contrast, only small differences in transparency occurred in 1992 among 1989 damage classes, and slightly greater values occurred in the light and moderate 1989 damage classes. Visual observations of trees with a range of crown transparency in the sugarbush in 1992 suggested that high values resulted from heavy thrips damage - foliage was typically undersized, tattered, and chlorotic on trees with the greatest transparency. These observations of damage occurrence indicate a lack of consistency in damage severity to individual trees between attacks in 1989 and 1992.

Severity of thrips damage to individual trees was related to variation in budburst phenology in previous studies on sugar maple seedlings and saplings (Kolb and Teulon 1991), and in this study sugarbush in 1991. In these cases, trees with early budburst were more prone to thrips damage than trees with late budburst because of greater synchrony of early budburst with emergence of adult thrips from the soil. Emergence of pear thrips from the soil in the sugarbush in 1991 was heaviest between April 2-9, and then declined to no emergence after May 1 (D. A. J. Teulon, Penn State University Dept. Entomology, unpublished data). Trees with the earliest phenology in 1991 broke bud between April 26 and April 30 when emergence was still occurring while trees with late phenology broke bud between May 12 and May 14, almost two weeks after emergence had ended. In contrast to 1991, there were no differences in thrips activity (number of oviposition sites) among trees with early and late budburst in 1992. In 1992, emergence of pear thrips from the soil was heaviest between April 10-17, and no emergence was detected after April 24 (D. A. J. Teulon, Penn State University Dept. Entomology, unpublished data). Trees with both early (May 4-6) and late phenology (May 11-14) in 1992 broke bud at least two weeks after emergence had ended, suggesting that budburst date had little influence on thrips feeding intensity in this year.

Flower production by all study trees in the sugarbush was heavy in 1992, while little to no flower production occurred in 1991. We speculate that variation in thrips damage severity among trees in 1992 may have been related to variations in flower production. This interpretation is supported by greater numbers of thrips oviposition sites in the upper compared with the middle crown in 1992, since flowering is typically heavier in upper branches. Pear thrips are voracious pollen feeders and a pollen heavy diet may increase larval production and consequent larval damage.

In our study, one year of heavy pear thrips damage had a detrimental impact on sugar maple health and syrup production for the next three years. The impact of pear thrips damage on other stands, however, may depend on their exposure to previous stress agents and management history.

ACKNOWLEDGEMENTS

This research was supported by funds from The Commonwealth of Pennsylvania, USDA Forest Service Grant No. 23-476, and a grant from the North American Maple Syrup Producers. We thank Ron Brenneman for providing his sugarbush for research. Valuable technical assistance in the study was provided by Dale Jeffery, Ed Simons, Brian Arnold, Elizabeth Vail, Durland Shumway, Rob Hellested, Chris Kilbride, Scott Burroughs, Dennis Hanvey, Jennifer Hanvey, Stacey Green, Matthew Miller, Amy Tyndall, and Robert Pfaff.

LITERATURE CITED

Allen, D. C., E. Bauce, and C. J. Barnett. In press. Sugar maple declines - causes, effects, and recommendations. In Manion and Lachance (eds.) Forest Declines.

Bailey, S. F. 1944. The pear thrips in California. Univ. of Cal. College of Agr. Exp. Sta. Bull. No. 687.

Bauce, E., and D. C. Allen. 1991. Etiology of a sugar maple decline. Can. J. For. Res. 21: 686-693.

Burns, B. S. 1991. Root starch in defoliated sugar maples following thrips damage. Pages 257-265 In B. L. Parker, M. Skinner, and T. Lewis (eds.), Towards Understanding Thysanoptera. USDA For. Ser. Gen. Tech. Rep. NE-147.

Chisholm, I. F., and T. Lewis. 1984. A new look at thrips (Thysanoptera) mouthparts, their action and effects of feeding on plant tissue. Bull. Entomol. Res. 74: 663-675.

Foster, S. W., and P. R. Jones. 1915. The life history and habits of the pear thrips in California. USDA Bull. No. 173.

Gregory, R. A., and P. M. Wargo. 1986. Timing of defoliation and its effect on bud development, starch reserves, and sap sugar concentration in sugar maple. Can. J. For. Res. 16: 10-17.

Heming, B. S. 1978. Structure and function of the mouthparts in larvae of *Haplothrips verbasci* (Osborn) (Thysanoptera, Tubulifera, Phlaeothripidae). J. Morph. 156: 1-38.

Herrick, G. T. 1988. Relationships between soil salinity, sap-sugar concentration, and health of declining sugar maples (*Acer saccharum*). Ohio J. Sci. 88: 192-194.

Houston, D. R., D. C. Allen, and D. Lachance. 1990. Sugarbush management: a guide to maintaining tree health. USDA Gen. Tech. Rep. NE-129.

Hunter, W. B., and D. E. Ullman. 1989. Analysis of mouthpart movements during feeding of *Frankliniella occidentalis* (Pergande) and *F. schultzei* Trybom (Thysanoptera:Thripidae). Int. J. Insect Morphol. and Embryol. 18: 161-171.

Johnson, R. W., M. T. Tyree, and M. A. Dixon. 1987. A requirement for sucrose in xylem sap flow from dormant maple trees. Plant Physiol. 84: 495-500.

Kolb, T. E., L. H. McCormick, and D. L. Shumway. 1991. Physiological responses of pear thrips-damaged sugar maples to light and water stress. Tree Physiology 9: 401-413.

Kolb, T. E., L. H. McCormick, E. E. Simons, and D. J. Jefferey. 1992. Impacts of pear thrips damage on root carbohydrate, sap, and crown characteristics of sugar maples in a Pennsylvania sugarbush. For. Sci. 38: 381-392.

Kolb, T. E., and D. A. J. Teulon. 1991. Relationship between sugar maple budburst phenology and pear thrips damage. Can. J. For. Res. 21: 1043-1048.

Kolb, T. E., and D. A. J. Teulon. 1992. Effects of temperature during budburst on pear thrips damage to sugar maple. Can. J. For. Res. In press.

Laudermilch, G. 1988. Thrips in Pennsylvania. Pages 36-62 In B. L. Parker, M. Skinner, and H. B. Teillon (eds.), The 1988 thrips infestation of sugar maple. VT Agr. Exp. Sta. Bull 696, Univ. VT, Burlington.

Marvin, J. W., M. F. Morselli, and M. C. Mathes. 1971. Rapid low temperature hydrolysis of starch to sugars in maple stems and in maple tissue cultures. Cryobiology 8: 339-344.

Millers, I., D. Lachance, W. G. Burkman, and D. C. Allen. 1991. North American Maple Project Cooperative Field Manual. USDA For. Ser. 43 p.

Nash, B., G. Stanosz, G. Taylor, and D. Davis. 1991. Association of a fungus with overstory sugar maple leaves injured by pear thrips in Pennsylvania. Phytopathology 81: 123 (abstract).

Parker, B. L. 1991. The pear thrips problem. Pages 179-188 In B. L. Parker, M. Skinner, and T. Lewis (eds.), Towards Understanding Thysanoptera. USDA For. Ser. Gen. Tech. Rep. NE-147.

Skinner M., B. L. Parker, and S. H. Wilmot. 1991. The life cycle of pear thrips, *Taeniothrips inconsequens* (Uzel) in Vermont. Pages 435-444 In B. L. Parker, M. Skinner, and T. Lewis (eds.), Towards Understanding Thysanoptera. USDA For. Ser. Gen. Tech. Rep. NE-147.

Smith, G., C. M. Petersen, R. Van Driesche, and C. Burnham. 1991. The relationship between measures of tree vigor and pear thrips damage in sugar maple. Pages 273-284 In B. L. Parker, M. Skinner, and T. Lewis (eds.), Towards Understanding Thysanoptera. USDA For. Ser. Gen. Tech. Rep. NE-147.

Tyree, M. T. 1983. Maple sap uptake, exudation, and pressure changes correlated with freezing exotherms and thawing endotherms. Plant Physiol. 73: 277-285.

Walters, R. S. 1982. Sugarbush management. Pages 25-37 In Sugar maple research: sap production, processing, and marketing of maple syrup. USDA Gen. Tech. Rep. NE-72.

Wargo, P. M. 1972. Defoliation-induced chemical changes in sugar maple roots stimulate growth of *Armillaria mellea.* Phytopathology 62: 1278-1283.

Forest Stand Conditions After 13 Years of Gypsy Moth Infestation

David L. Feicht, Sandra L.C. Fosbroke, and Mark J. Twery

Abstract: Of 603 central Pennsylvania plots that were established in 1978 to measure the short-term impact of repeated gypsy moth (*Lymantria dispar*) defoliation, 228 were selected for continued study in 1985. Individual observations of defoliation and tree vigor were continued through 1992. Although two gypsy moth outbreaks occurred across central Pennsylvania from 1978 to 1990, only 22% of the plots were defoliated severely for more than one year. Net change in basal area/acre from 1978 to 1990 (including both accretion and ingrowth) ranged from +70 to -92% depending on defoliation severity and frequency. Oak species were defoliated disproportionately and had higher mortality rates than non-oak species. Eighty-eight percent of ingrowth trees were of commercial hardwood species (3.3% oak), 4.3% were of commercial softwoods, and 7.1% were of noncommercial species. Regeneration surveys conducted in 1989 and 1992 showed that 77 and 65%, respectively, of the regeneration plots within stands with severe mortality (> 30% basal area/acre) are adequately stocked with commercial hardwood species; 16 and 25% of the regeneration plots in 1989 and 1992, respectively, were fully stocked with oak species. As of 1990, 77.6% of the plots contained fully stocked or overstocked overstories despite two waves of gypsy moth infestation and resultant mortality. As of 1990, residual stands still contain a viable oak component (1990 ave. = 58% basal area/acre in oak), though ingrowth and advanced regeneration data indicate that future stands may have more red maple, birch, and black gum stems, and thus be better able to withstand future gypsy moth infestations.

BACKGROUND

In 1978, a network of 603 plots was established by the USDA Forest Service in advance of approaching gypsy moth populations in central Pennsylvania to monitor impacts and to refine susceptibility and hazard-rating procedures developed in northeastern Pennsylvania by Herrick and others (1979). A total of 201 stand locations was established between State College, Lewistown, and Carlisle in the heart of Pennsylvania's oak forest. Three permanent, 1/10th-acre plots were established at each location. Data were collected on 26 variables in order to predict stand and tree predisposition to defoliation and mortality. Measurements were taken annually through 1982 with the cooperation of the USDA Forest Service, Northeastern Area State and Private Forestry (NA S&PF), Forest Insect and Disease Management staff. Data were collected in 1983 and 1984 by the Pennsylvania Department of Environmental Resources' Bureau of Forestry staff through a memorandum of understanding with NA S&PF. In 1985, the USDA Forest Service's Forest Inventory and Analysis unit took the final measurements on the plots and added new ingrowth stems to the data set.

At the request of the Pennsylvania Gypsy Moth Advisory Committee (February 1986 meeting), the Forest Service agreed to continue monitoring a subset (228 plots) of the original plots to accumulate more data on the long-term impact of defoliation and mortality. Seventy six of the original plots that received at least one defoliation in excess of 60% were included in the subset in order to achieve the objectives of assessing long-term impacts. The balance of the subsample was equally divided between plots that had only been defoliated moderately (30 - 60%) and those that had never been defoliated more than 30% since 1978. The subset of plots is located in a six-county area in central Pennsylvania and fall within the boundaries of the Tuscarora and Bald Eagle State Forests. This area is part of the Ridge and Valley physiographic province and includes primarily mixed oak forests, including some of the most extensive and highest quality oak forests in Pennsylvania (Pennsylvania Bur. of For. 1983). USDA Forest Service Research Work Unit 4557 (Silvicultural Options for the Gypsy Moth) in Morgantown, WV, was responsible for planning, organizing, and coordinating continued data collection on the subset. The Advisory Committee secured agreements from the private sector as well as the Pennsylvania Bureau of Forestry to provide personnel to assist in the collection of field data. Under this cooperative arrangement, data have been collected annually on this subsample through 1992. This paper describes changes in overstory stand conditions from 1978 to 1990 as well as results from regeneration surveys conducted in 1989 and 1992 on the subsample.

METHODS

During plot establishment in 1978, all trees greater than 3 inches dbh on each 1/10th-acre plot were tallied. Measurements of tree defoliation and vigor (two of the original 26 variables measured in 1978) were continued on the subset from 1986 to 1990 to monitor long-term impacts. Defoliation was recorded to the nearest 10% for each tree from 1978 through 1990 except for 1985. Plot-level defoliation estimates were used in 1985 based on Pennsylvania Bureau of Forestry aerial sketch mapping for that year plus individual-tree defoliation subsamples that were taken on approximately 15% of the plots for a concurrent study. On both a tree- and plot-level basis, defoliation less than 30% is classified as low, defoliation between 30% and 60% is considered moderate, and defoliation exceeding 60% is severe. Stems that had grown larger than 3 inches dbh were added to overstory tallies in both 1985 and 1990. Stand stocking was calculated based on stocking guides developed by Roach and Gingrich (1968) that incorporate basal area, average stand diameter, and number of stems. Regeneration data were not collected in 1978, but regeneration surveys were conducted in 1989 and 1992 to evaluate understory conditions in response to overstory mortality. Relative frequencies of live stems of all woody species tallied in overstory, ingrowth, and regeneration sampling are listed in Appendix A.

INITIAL OVERSTORY STAND CONDITIONS

Average stand age in 1978 was approximately 70 years (range = 33 - 161 years). The average tree diameter over all plots in 1978 was 7.0 inches for all species and 8.4 inches for oak species. The basal area/acre (stems $\geq$3 inches dbh) of all species in 1978 ranged from 29 to 184 ft^2/acre with a mean of 87 ft^2/acre (Figure 1). The initial distribution of oak basal area ranged from 0 (six plots contained no oak) to 143 ft^2/acre with a mean of 60 ft^2/acre, representing a range of 0 to 97% oak basal area/acre with an average of 68%. In 1978, 28.1% of the plots were overstocked, 56.1% were fully stocked, and 15.8% were considered understocked.

DEFOLIATION HISTORY

Defoliation patterns over the plots from 1978 through 1990 generally mirror defoliation patterns over the six-county area throughout which the plots are distributed (Figure 2). Gypsy moth defoliation reached outbreak levels in 1981 when 34% of the plots received severe (greater than 60%) defoliation and again in 1986 when 18% of the plots received defoliation in excess of 60%. Twenty six of the plots were included in the Pennsylvania gypsy moth suppression program in 1986 because high egg mass counts indicated that heavy defoliation was imminent. The percentage of plots receiving severe defoliation in 1986 would likely have been closer to 30% if these plots had not been sprayed for gypsy moth control.

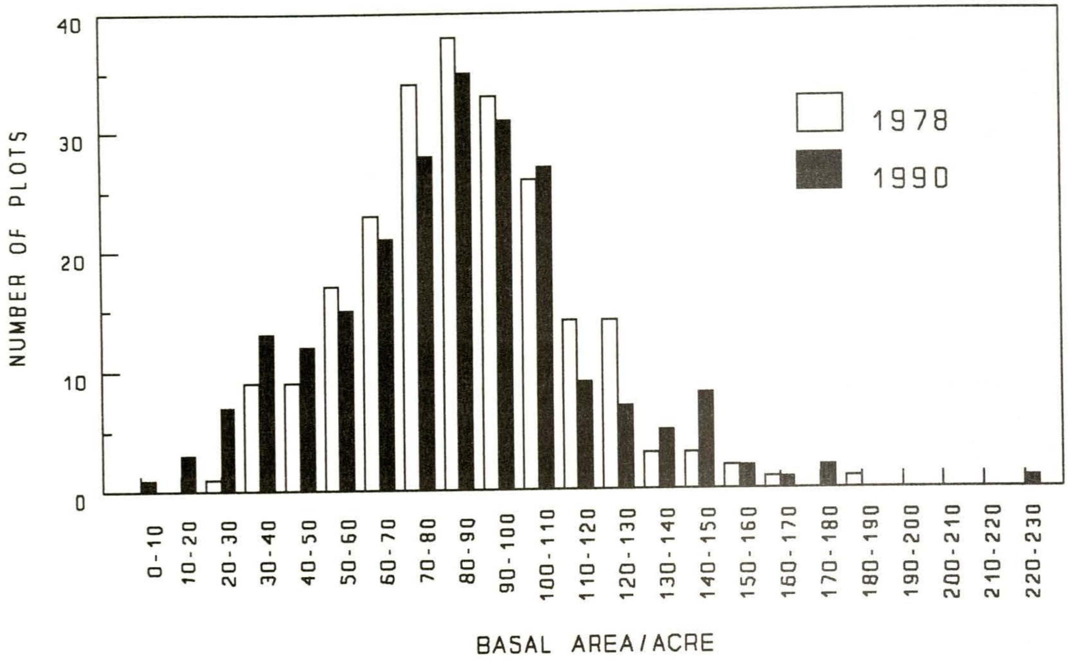


Figure 1.—Live basal area/acre for all species in 1978 and 1990.

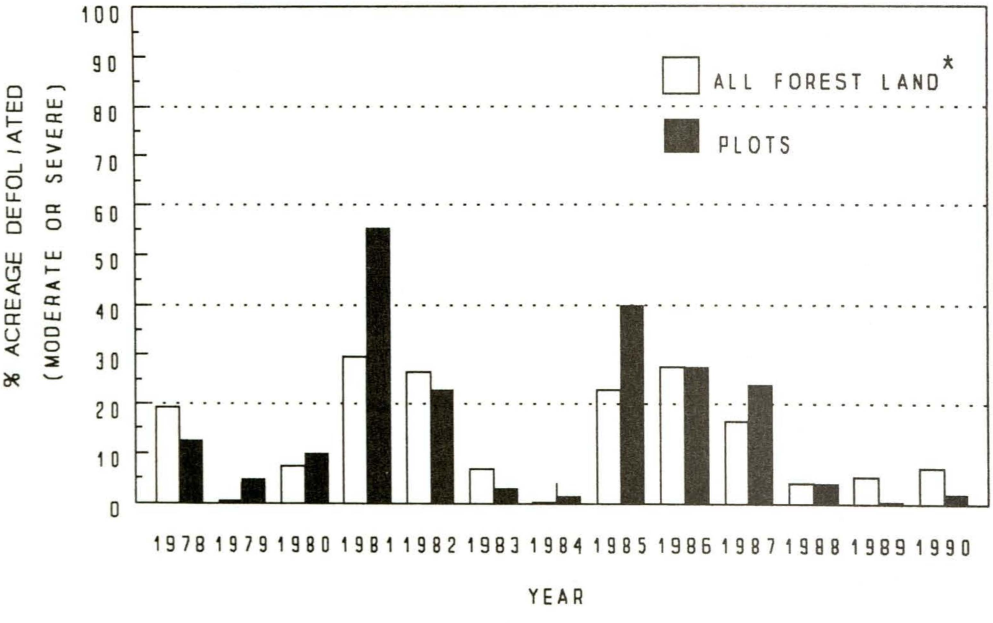


Figure 2.—Percent forested acreage receiving moderate or severe defoliation from 1978 to 1990.

*6-county area has 916,000 acres of forest land (Powell and Considine 1982).

Defoliation classes were established and calculated for each plot based on its defoliation history to assess the impact of defoliation on the forest. These classes take into account the severity and frequency of defoliation (Table 1). Tables 2 and 3 indicate the number of plots that fell within each of these defoliation classes during two time frames: from 1978 to 1985 and from 1985 to 1990. From 1978 to 1985, 30% of the plots received no defoliation greater than 30% (defoliation class 0). Another 13% of the plots received only one moderate defoliation (defoliation class 1). The other 57% of the plots received at least one year of heavy defoliation or two years of moderate defoliation, or more (defoliation classes 2 and greater). From 1985 to 1990, 42% of the plots were placed in defoliation class 0. Twenty-two percent of the plots were placed in defoliation class 1. The other 36% of the plots were placed in defoliation classes greater than 1.

Table 1.—Defoliation classes assigned to individual plots based on the number and severity of defoliations (H=high, M=Moderate)

CLASS 0	No defoliation >30%
CLASS 1	1 year M
CLASS 2	1 year H (or) 2 years M
CLASS 3	1 year H & 1 year M (or) 3 years M
CLASS 4	2 years H (or) 1 year H & 2 years M (or) 4 years M
CLASS 5	2 years H & 1 year M (or) 1 year H & 3 years M (or) 5 years M
CLASS 6	3 years H (or) 2 years H & 2 years M (or) 1 year H & 4 years M
CLASS 7	3 years H & 1 year M (or) 2 years H & 3 years M
CLASS 8	4 years H (or) 3 years H & 2 years M (or) 2 years H & 4 years M
CLASS 9	4 years H & 1 year M

MORTALITY

The likely effect of repeated defoliation is mortality. Mortality from gypsy moth defoliation has been described in various forests throughout infested areas (Baker 1941; Campbell and Valentine 1972; Corliss 1955; Fosbroke and Hicks 1989; Fosbroke and others 1991; Kegg 1971, 1973; Nichols 1961; Quimby 1990; Stephens 1971, 1981; Twery 1991). The vastly different parameters used in these studies to report mortality preclude comparison, but they agree that mortality (consisting primarily of *Quercus* spp.) is high in areas recently invaded by the gypsy moth. In this study, the average percent change of plot live basal area consistently increased with increasing defoliation frequency and intensity (Tables 2 - 3). This relationship was observed from 1978 to 1985 as well as from 1985 to 1990, the time frames used to bracket the two defoliation episodes separately. The average percent change was calculated both with 'no growth', where basal area change was based on initial tree diameter only, and with 'growth', where beginning and ending tree diameters were used, thereby modifying the net basal area change by diameter growth of the remaining live trees. The tables show that although the average percent change increases with the severity and intensity of defoliation, growth of the residual trees modifies this impact; in fact, in plots that received one year of defoliation or less from 1978 to 1985, a positive value in overall basal area change is reflected. Gottschalk (1989) found that overall mortality is directly influenced by the frequency and intensity of defoliation to a much greater degree than by stocking or recent cutting activities; although we have no data to draw conclusions about the effect of recent cutting activities, these data do support his conclusion that defoliation frequency and intensity directly affect mortality.

Table 2.—Mean percent change in basal area of all trees on a plot within a defoliation class, 1978-85

	No growth			**Modified by growth[1]**	
Class	**SE[2]**	**% Change**	**Frequency**	**% Change**	**SE[2]**
0	1.12	-8.4	67	+9.1	1.50
1	1.89	-9.5	30	+7.5	1.88
2	1.61	-13.5	51	+1.4	1.93
3	2.35	-18.6	31	-5.3	2.57
4	4.42	-23.5	20	-10.5	5.26
5	4.99	-37.2	5	-22.7	6.15
6	7.58	-46.3	9	-35.8	8.34
7	7.65	-62.0	6	-55.5	8.54
8	7.30	-50.5	5	-43.7	7.41
9	7.77	-77.5	4	-71.6	9.21

Table 3.—Mean percent change in basal area of all trees on a plot within a defoliation class, 1985-90

	No growth			**Modified by growth[1]**	
Class	**SE[2]**	**% Change**	**Frequency**	**% Change**	**SE[2]**
0	0.45	-3.2	94	+7.6	1.61
1	1.19	-5.4	49	+4.5	1.14
2	2.69	-11.7	31	-2.5	3.05
3	4.72	-25.6	14	-16.9	5.34
4	5.12	-23.1	20	-14.6	5.19
5	9.40	-26.6	9	-18.8	8.68
6	11.52	-59.7	4	-56.8	12.52
7	.	-88.1	1	-81.2	.

[1] Growth includes only accretion on residual trees and not ingrowths.

[2] SE = Standard error of the mean.

By 1990, live basal area/acre ranged from 10 to 224 ft^2/acre, with an average of 84 ft^2/acre (Figure 1). On average, overstory stocking levels after 13 years of gypsy moth infestation did not change substantially. There was a reduction in the percentage of both overstocked stands (28.1 to 27.2%) and fully stocked stands (56.1 to 50.4%), while the percentage of understocked stands increased by 5% from 15.8 to 22.4%. These stocking levels are comparable to data from the Pocono Mountains in eastern Pennsylvania (Gansner and others 1983); these results also support Herrick and Gansner's (1988) conclusion that overall stocking levels on the original 603 plots from 1978 to 1985 did not change substantially.

We classified overstory mortality into three classes based on basal area loss per acre as of 1990: low (less than 15%), moderate (15 to 30%) and severe (greater than 30%). The severity of net overall mortality ranged up to a 92% loss in basal area per acre depending on the frequency and severity of defoliation. However, the net effect of this mortality on the oak component across all the plots is not evident when all species are combined (Figure 1). Mortality is distributed disproportionately among species; species preferred by the gypsy moth (*Quercus* spp.) were more heavily defoliated (Gansner and Herrick 1985) and subsequently had higher basal area losses than non-oak species (Figure 3). Sixty-five percent of all stems that died from 1978 to 1990 were oaks; the species with the next highest stem mortality was sassafras (7.7% of all stems), followed by flowering dogwood (6.3%) and red maple (5.1%). Even after growth and ingrowths are included, 110 plots (48%) had some degree of oak mortality; 41 plots (18%) had oak mortality in excess of 30 ft^2 of basal area/acre (Figure 3). By contrast, 205 plots (90%) accrued a net increase in live basal area of non-oak species, while only 112 plots (49%) recorded a similar net increase in oak live basal area (Figure 3). Overall, non-oak species were defoliated less severely and less frequently, suffered less mortality, and are growing at better rates than oak (Gasner and Herrick, and Figure 3).

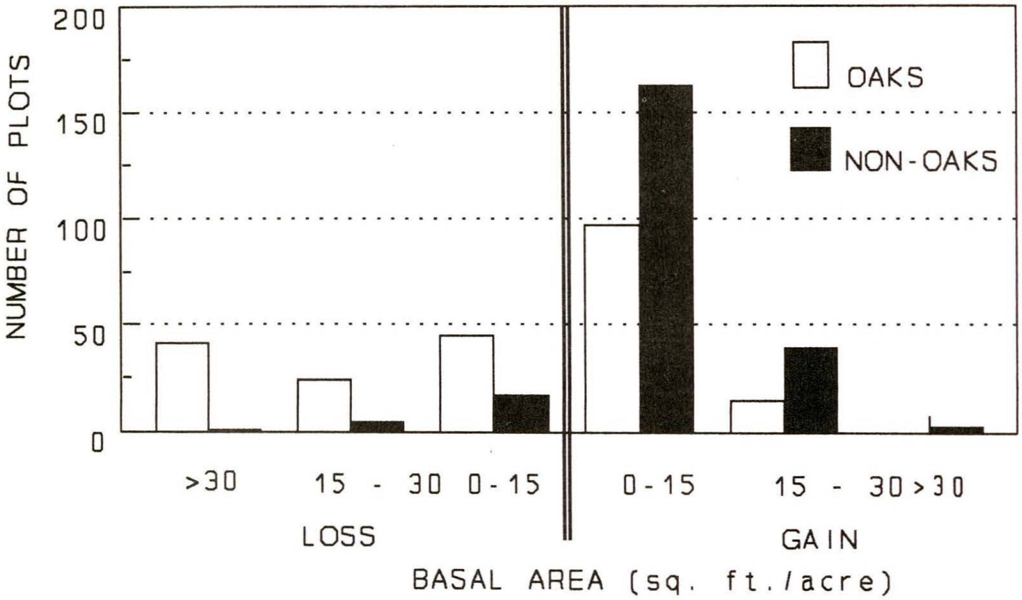


Figure 3.—Net change in live basal area/acre for oak and non-oak species from 1978 to 1990.

STAND RECOVERY

Following tree mortality in general, forest stands recover as other plants occupy the growing space. Some space will be occupied by crown and root expansion of existing canopy trees. Some will be claimed by growth of small, previously established plants into measurable sizes, and some will be occupied by new individuals that establish after an opening is created. Within this study, species composition is shifting in response to mortality on several fronts: survival and growth of residual overstory trees, the recruitment of ingrowth stems into stands, and the establishment of new regeneration in the understory.

Residual Stands

Despite severe mortality among oaks, the percentage of oak basal area in overall stand composition on average was 58% in 1990 over all mortality classes (Figure 4a). Even within the severe mortality class, the percentage of oak basal area remained above 43% in 1990 (Figure 4d). However, there is a relative increase in non-oak species, whether expressed as a percentage of live basal area (Figure 4) or as the number of stems per acre (Figure 5). Chi-square analysis between species distribution in 1978 and 1990 by mortality class (Figures 4 - 5) showed no significant changes within all mortality classes combined or within the low mortality class, whether expressed as a percentage of live basal area or percent of stems. Stands within the moderate and severe mortality classes showed significant changes in percent basal area distribution of all species ($X^2 = 27.97$ and 129.22, respectively, df=8, $P < 0.005$). When expressed as percent of stems, these two classes also showed similar changes ($X^2 = 58.33$ and 91.37, respectively, df=8, $P < 0.005$). This shift among oak and non-oak species is enhanced as overstory mortality increases (Figures 4 - 5). Red maple by far shows the greatest percent increase, followed by sweet birch and black gum. The response by red maple to both defoliation and mortality is consistent with observations by Collins (1961), who found that red maple in the understory responded with increased growth and higher survival rates under recently defoliated oak stands, primarily due to increased light intensity.

Ingrowth

The species mix of newly recruited ingrowth stems in 1985 and 1990 augments the increasing abundance of non-oak species in the overstory following gypsy moth defoliation and mortality (Table 4, Figure 6). On average, red maple is once again the most numerous species, representing 48% of all new stems, followed by black gum (16.5%), sweet birch (13.6%), oaks (3.3%) and sassafras (3.2%). Softwoods, although a small component of our sample, have increased from 1985 to 1990. Yellow-poplar similarly increased in frequency from 1985 to 1990, up from 0.4% in 1985 to 5% of new ingrowths in 1990. The distribution of ingrowth stems is relatively uniform across all mortality classes. The mean number of ingrowth stems added to plots within the low, moderate, and severe mortality classes is 5.1, 5.9, and 4.5, respectively.

Table 4.—Composition of ingrowth stems across all plots by species group and inventory year

	1985	**1990**
Commercial hardwoods	91.0%	82.0%
Oaks	3.6%	2.6%
Non-oaks	87.9%	79.3%
Softwoods	2.8%	8.0%
Noncommercial species	5.7%	10.0%

NOTE: 783 ingrowth stems added in 1985 on 228 plots.
343 ingrowth stems added in 1990 on 198 plots.

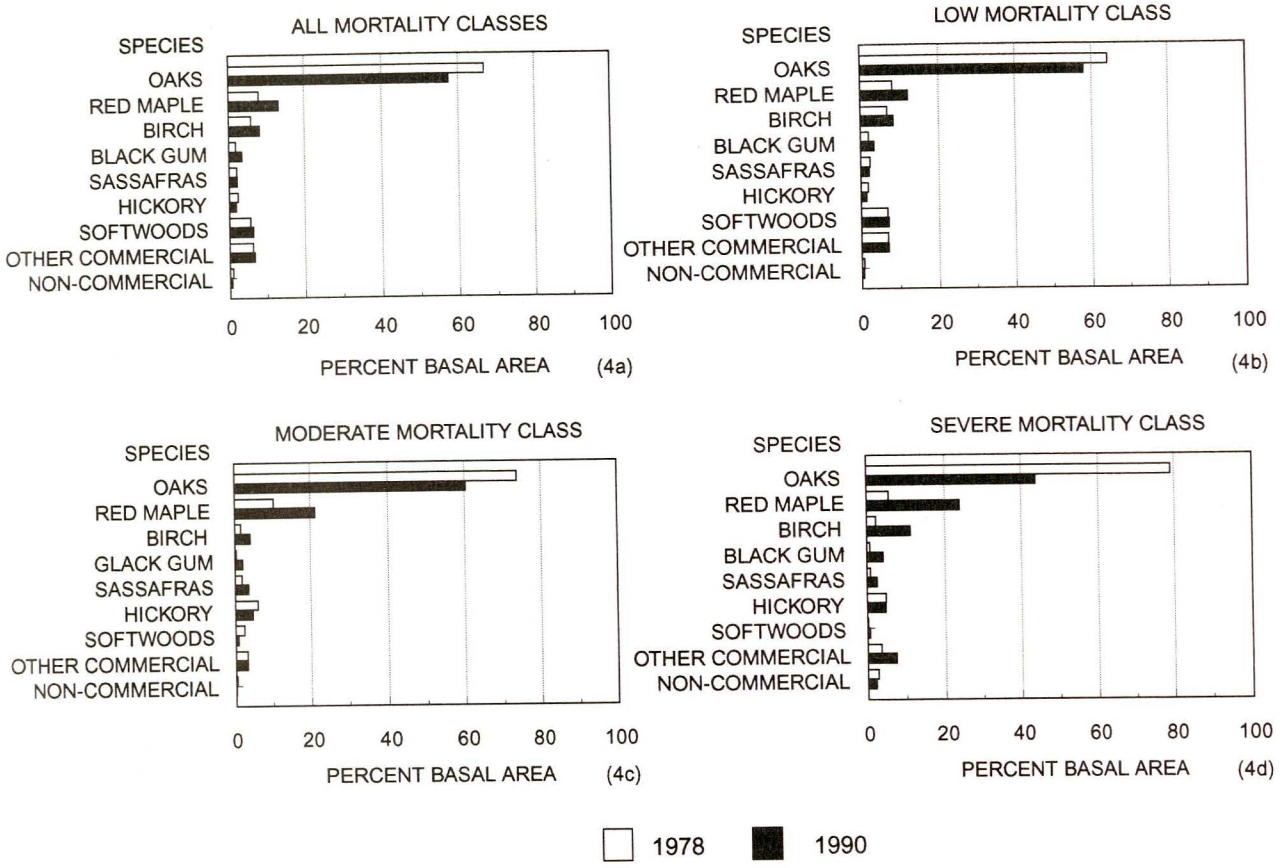


Figure 4. Percent live basal area/acre in 1978 and 1990 by mortality class.

Figure 4.—Percent live basal area/acre in 1978 and 1990 by mortality class.

Advanced Regeneration

The development of advanced regeneration in the understory is more volatile than ingrowths in response to severe defoliation and mortality. New seedling establishment is more dependent on abundant seed, whether new or stored in the litter, as well as on the proper conditions for establishment and development; seedlings also are more susceptible to deer browsing than ingrowth trees.

The species mix of new seedlings is similar to that of the ingrowth stems that are responding to changing growing conditions in this study. Species composition of regeneration stems is also consistent with observations by Ehrenfeld (1980); stem recruitment in this study is almost exclusively from those species that existed in the original stand. Hix and others (1991) also found that one to three years after gypsy moth-caused overstory mortality, new species were not being established among regeneration stems. In 1989, nearly 51% of the regeneration stems sampled (excluding blueberry, *Viburnum* spp. and laurel) were red maple, 12.2% were oaks, 5.2% were sassafras, 4.4% were birches, and 2.3% were black gum. In 1992, there was a decline in the total number of regeneration stems sampled; however, red maple still made up the greatest percentage of stems (49.4%), followed by all oaks (11.5%), birches (10.9%), sassafras (2.8%), and black gum (0.9%) (Figure 7). Six to seven years after severe overstory mortality, Allen and Bowersox (1989) sampled understory vegetation beneath understocked stands in the Ridge and Valley physiographic province; although they found similar percentages of red maple stems (42%) and all oak stems (14%), they had a greater percentage of birch stems (25%) than we found in this study. Hix and others (1991) found that red maple was the most common commercial tree species present one to three years following overstory mortality in the Ridge and Valley physiographic province.

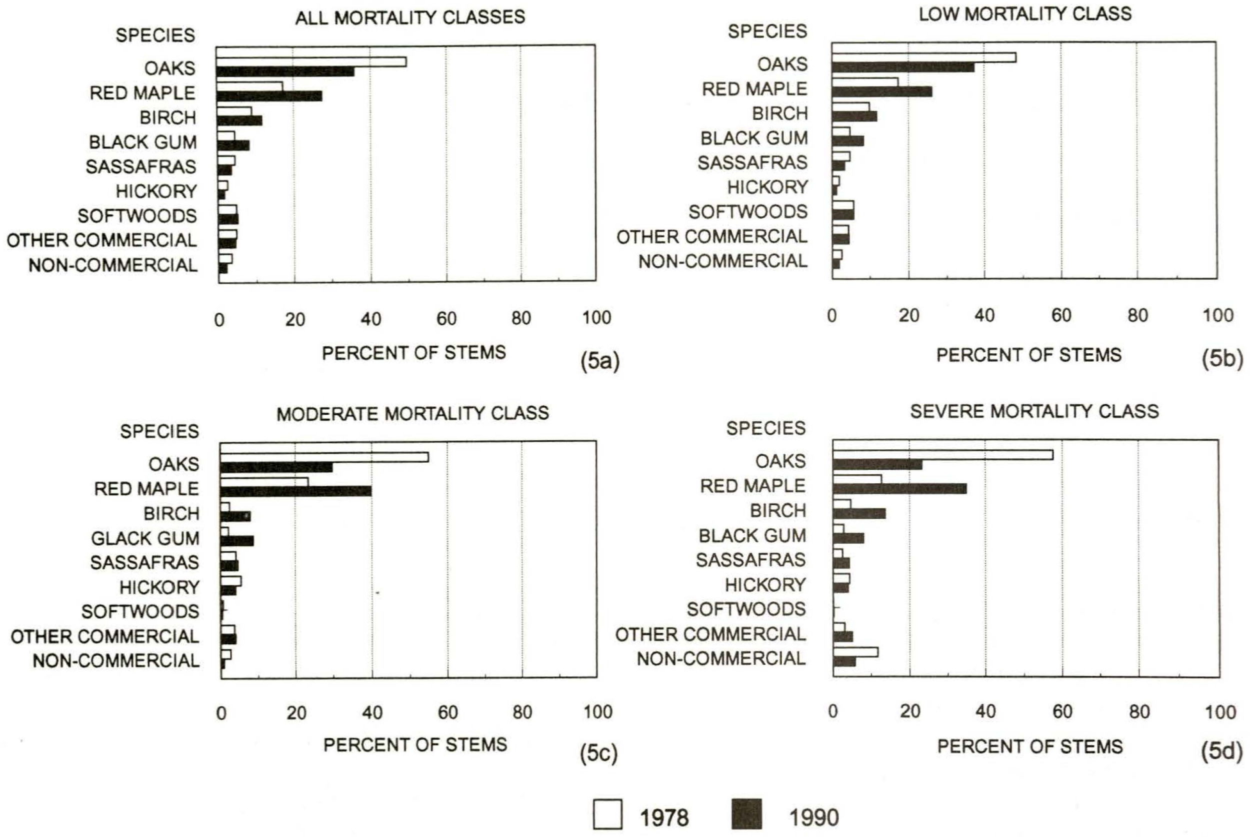


Figure 5.—Percent of live stems in 1978 and 1990 by mortality class.

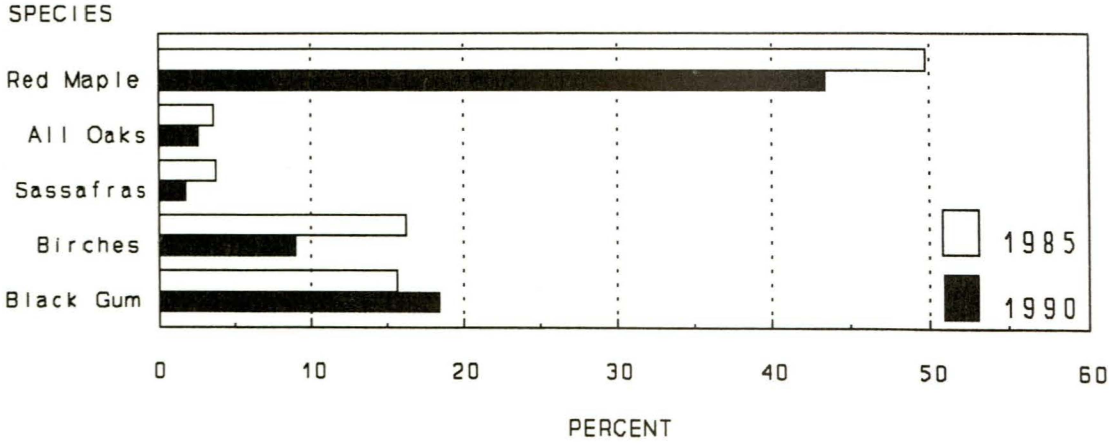


Figure 6.—Percentage of ingrowth stems for selected species in 1985 and 1990.

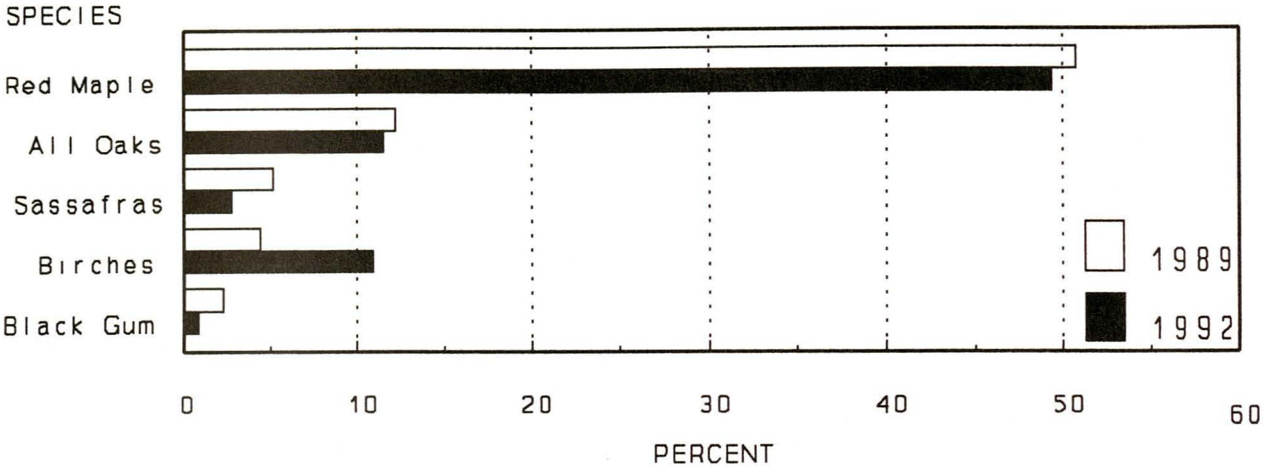


Figure 7.—Percentage of regeneration stems for selected species in 1989 and 1992.

To determine the potential influence of these stems in continued stand development, we used regeneration stocking criteria developed to predict the probable future success of both oak and commercial regeneration stems (Marquis and Bjorkbom 1982; Sander and others 1976, 1984). Not surprisingly, the number of regeneration plots that met any of the fully stocked criteria generally increased within a given year as mortality increased, though the difference between the severe and moderate mortality classes was minimal (Tables 5 - 6). Because of the general decline in the total number of seedlings sampled in 1992, fewer plots met the stocking guideline criteria for full stocking in that year. It is encouraging that the number of plots considered "fully stocked" with oak regeneration in areas that had severe mortality increased from 16 to 25% between 1989 and 1992. Allen and Bowersox (1989) also evaluated regeneration stocking success; six to seven years after severe overstory mortality had occurred, 83% of their plots were considered fully stocked with commercial species. Nineteen percent of their regeneration plots were considered fully stocked with oak species.

Table 5.—Percentage of regeneration plots meeting any success criteria for all commercial stems

	1989	**1992**
All mortality classes	43%	32%
Severe mortality	77%	65%
Moderate mortality	72%	69%
Low mortality	33%	25%

Table 6.—Percentage of regeneration plots meeting any success criteria (oak stems only)

	1989	1992
All mortality classes	6%	5%
Severe mortality	16%	25%
Moderate mortality	17%	15%
Low mortality	3%	2%

CONCLUSIONS

Although two gypsy moth outbreaks occurred across central Pennsylvania from 1978 to 1990, only 22% of the plots were defoliated heavily for more than one year. Twenty-six percent of the plots never received defoliation greater than 30% over the 13-year period. In any given year, the percentage of plots that received severe defoliation never exceeded 34%. Basal area mortality was not distributed uniformly and ranged from 3 to 90%. Seventy-six percent of the plots had low mortality (< 15% basal area/acre) and 7% had moderate mortality (15 - 30% basal area/acre), while only 17% of the plots had severe mortality (> 30% basal area/acre). The percentage of stands at or above full overstory stocking in 1990 was 78%, only a 6% drop from 1978. Growth occurred primarily on non-oak species (red maples, black gum and sweet birch) as they responded to the defoliation and mortality of oak. Non-oak species are rapidly replacing basal-area losses and increasing in frequency within the stands. Oak is still a major component of the stands, however; the mean percentage of oak basal area in the overstory dropped from 68% in 1978 to only 58% in 1990.

Overall, the integrity of these mixed oak forests has been sustained with little impact over the majority of the study area, where mortality was light and scattered. To the manager of a large state forest or the owner of a large tract of commercial timberland, losing 30 to 50% of the basal area in a few stands is not catastrophic. For one of the 490,100 small woodland owners in Pennsylvania to suffer such a loss could indeed be catastrophic from a timber management perspective. Nearly 30% of small woodland owners have aesthetics as their major management objective, however (Birch and Dennis 1980). Hollenhorst and others (1993) found that as basal area mortality approached 30 to 40% at southwestern Pennsylvania sites within the Central Appalachian Plateau physiographic region, scenic preferences and appeal for visitation increased; once basal area mortality exceeded this range, however, these ratings dropped abruptly. Based on this criterion, 83% of the plots have not suffered from the standpoint of visual appeal.

At some level of mortality, regardless of the owner, forced liquidation of stands may be the only recourse from a timber management perspective. Between 1985 and 1990, 30 of our 228 plots were involved in commercial salvage operations. Stands with severe mortality where logistics or accessibility precluded salvage were left to recover naturally. In areas where severe mortality did occur, losses are quickly being replaced by residual overstory tree growth, by the ingrowth of new stems, and by the establishment of new regeneration.

Although oak has been a strong competitor in lumber production for many years, other species cannot be discounted out of hand. Species that are increasing in abundance within these stands are traditionally lower-value commercial species. Red maple, an opportunistic species often viewed unfavorably from a commercial standpoint, is finding its way into many markets. These range from structural uses, such as timber bridges, to the increasing white wood export market in the Pacific Rim countries. As a result, red maple has been steadily increasing in value for the last five years (Weekly Hardwood Review 1992).

Effects of these changing stand conditions, primarily shifts in species composition, extend beyond the plant communities and commercial considerations to also influence wildlife populations that are sustained by forests as well as other forest uses, such as recreation (Hollenhorst and others 1993). One of the principal contributions of these forests to wildlife is the production of mast. From a mast-production standpoint, many of these stands may well have been improved by undergoing a thinning from below which eliminated many of the poor crowned, unproductive mast-producing trees. Using stand mortality data from these plots, Gottschalk (1990) found that stands with less than 25% mortality initially lose 10% of their acorn production capacity but that growth compensates for that loss, providing a 20% increase in capacity seven years later.

Overall, these stands demonstrate just how resilient the eastern hardwood forest is. In Pennsylvania's 1990 damage appraisal report, John Quimby states, after surveying several forest districts (including the Tuscarora and the Bald Eagle), "District 3 (Tuscarora State Forest) forests appear quite healthy and fully stocked. Oak is still the predominant species in most stands...District 7 (Bald Eagle State Forest)...[has] lots of healthy appearing trees, including oak with white pine coming in almost everywhere. The view from overlooks, roadsides, and the Sand Mountain [fire] tower is one of well-stocked stands of mixed oak" (Quimby 1990). Quimby's observations may be anecdotal, but the data from our study lend some credence to them.

ACKNOWLEDGEMENTS

We gratefully acknowledge suggestions and reviews by Rose-Marie Muzika, Jeff Witcosky, John Ghent and Kurt Gottschalk. We also acknowledge Mary-Carol Koesler (formerly with International Paper Co.), Robert McCullough (Glatfelter Paper Co.), Tom Strasbaugh, Bob Kurilla and Tom Fuller (Pennsylvania Bureau of Forestry) for their dedicated assistance, as well as the many seasonal employees who enabled us to continue with the field data collection on an annual basis.

LITERATURE CITED

Allen, D., and T. Bowersox. 1989. Regeneration in oak stands following gypsy moth defoliation. P. 67-73 in Proc., seventh central hardwood forest conference, March 5-8, 1989, Carbondale, IL. USDA For. Serv. Gen. Tech. Rep. NC-13

Baker, W.L. 1941. Effects of gypsy moth defoliation on certain forest trees. J. For. 39: 1017-1022.

Birch, T.W., and D.F. DENNIS. 1980. The forest-land owners of Pennsylvania. USDA For. Serv. Res. Bull. NE-66. 90 p.

Campbell, R.W., and H.T. Valentine. 1972. Tree condition and mortality following defoliation by the gypsy moth. USDA For. Serv. Res. Pap. NE-236. 331 p.

Collins, S. 1961. Benefits to understory from canopy defoliation by gypsy moth larvae. Ecology 42: 836-838.

Corliss, J.M. 1955. Damage to our forests caused by the gypsy moth in 1953. J. Econ. Entomol. 48: 263-264.

Ehrenfeld, J.G. 1980. Understory response to canopy gaps of varying size in a mature oak forest. Torr. Bot. Club Bull. 107: 29-41.

Fosbroke, D.E., and R.R. Hicks, Jr. 1989. Tree mortality following gypsy moth defoliation in southwestern Pennsylvania. P. 74-80 in Proc., seventh central hardwoodforest conference (G. Rink and C.A. Budelsky, eds.), March 5-8, 1989, Carbondale, IL. USDA For. Serv. Gen. Tech. Rep. NC-132.

Fosbroke, D.E., R.R. Hicks, Jr., and K.W. Gottschalk. 1991. Predicting tree mortality following gypsy moth defoliation. P. 583-585 in Proc., eighth central hardwood forest conference (L.H. McCormick and K.W. Gottschalk, eds.), March 4-6, 1991, University Park, PA. USDA For. Serv. Gen. Tech. Rep. NE-148.

Gansner, D.A., O.W. Herrick., P.S. Debald, and R.E. Acciavatti. 1983. Changes in forest condition associated with gypsy moth. J. For. 81: 155-157.

Gansner, D.A., and O.W. Herrick. 1985. Host preferences of gypsy moth on a new frontier of infestation. USDA For. Serv. Res. Note NE-330. 3 p.

Gottschalk, K.W. 1989. Effects of previous stand management on mortality following gypsy moth defoliation: preliminary results. P. 573-578 in Proc., fifth biennial southern silvicultural research conference, Nov. 1-3, 1988, Memphis, TN. USDA For. Serv. Gen. Tech. Rep. SO-74.

Gottschalk, K.W. 1990. Gypsy moth effects on mast production. P. 42-50 in Proc., southern appalachian mast management workshop (C.E. McGee, ed.), August 14-16, 1989, Knoxville, TN. Univ. of Tennessee.

Herrick, O.W., and D.A. Gansner. 1988. Changes in forest condition associated with gypsy moth on new frontiers of infestation. N. J. Appl. For. 5(1): 59- 61.

Herrick, O.W., D.A. Gansner, and P.S. Debald. 1979. Predicting stand losses from the gypsy moth: An application of automatic interaction detection (AID). J. For. 77: 91-94.

Hix, D.M., D.E. Fosbroke, R.R. Hicks, Jr., and K.W. Gottschalk. 1991. Development of regeneration following gypsy moth defoliation of Appalachian Plateau and Ridge and Valley hardwood stands. P. 347-359 in Proc., eighth central hardwood forest conference (L.H. McCormick and K.W. Gottschalk, eds), March 4-6, 1991, University Park, PA. USDA For. Serv. Gen. Tech. Rep. NE-148.

Hollenhorst, S.J., S.M. Brock, W.A. Freimund, and M.J. Twery. 1993. Predicting the effects of gypsy moth on near-view aesthetic preferences and recreation appeal. For. Sci. 39: 28-40.

Kegg, J.D. 1971. The impact of the gypsy moth: repeated defoliation of oaks in New Jersey. J. For. 69: 852-854.

Kegg, J.D. 1973. Oak mortality caused by repeated gypsy moth defoliation in New Jersey. J. Econ. Entomol. 66: 639-641.

Marquis, D.A., and J.C. Bjorkbom. 1982. Guidelines for evaluating regeneration before and after clearcutting Allegheny hardwoods. USDA For. Serv. Res. Note NE-307. 4 p.

Nichols, J.O. 1961. The gypsy moth in Pennsylvania, its history and eradication. Pennsylvania Dep. Agric. Misc. Bull. 4404. 82 p.

Pennsylvania Bureau of Forestry. 1983. Bureau of Forestry annual report. Pennsylvania Bur. For., Harrisburg. 48 p.

Powell, D.S., and T.J. Considine, Jr. 1982. An analysis of Pennsylvania's forest resources. USDA For. Serv. Res. Bull. NE-69. 97 p.

Quimby, J.W. 1990. Tree mortality following gypsy moth epidemics-1990. Pennsylvania Bur. For., Div. For. Pest Manage. Rep. 50 p.

Roach, B.A., and S.A. Gingrich. 1968. Even-aged silviculture for upland central hardwoods. U. S. Dep. Agric., Agric. Handb. 355. 39 p.

Sander, I.L., P.S. Johnson, and R.F. Watt. 1976. A guide for evaluating the adequacy of oak advance reproduction. USDA For. Serv. Gen. Tech. Rep. NC-23. 7 p.

Sander, I.L., P.S. Johnson, and R. Rogers. 1984. Evaluating oak advance reproduction in the Missouri Ozarks. USDA For. Serv. Res. Pap. NC-251. 16 p.

Stephens, G.R. 1971. The relation of insect defoliation to mortality in Connecticut forests. Connecticut Agric. Exp. Stn. Bull. 723. 16 p.

Stephens, G.R. 1981. Defoliation and mortality in Connecticut forests. Connecticut Agric. Exp. Stn. Bull. 796. 13 p.

Twery, M.J. 1991. Effects of defoliation by gypsy moth. P. 27-39 in Proc., USDA interagency gypsy moth research review (K.W. Gottschalk, M.J. Twery, and S.I. Smith, eds.), Jan. 22-25, 1990, East Windsor, CT. USDA For. Serv. Gen. Tech. Rep. NE-146.

Weekly Hardwood Review. 1992. Oct. 17-20. Weekly Hardwood Rev. 55 p.

Appendix A.—Relative frquency of live stems (all stands/mortality classes)

Name	Overstory		Ingrowth		Regeneration[a]	
	1978	1990	1985	1990	1989	1992
Chestnut oak	32.5	22.5	1.4	0.6	8.9	6.7
Red maple	16.6	26.8	49.7	43.4	50.7	49.4
N. red oak	9.9	9.1	1.5	1.8	2.3	2.5
Black birch	8.9	11.7	15.6	9.0	4.2	10.8
Sassafras	4.7	3.5	3.8	1.8	5.2	2.8
Black gum	4.3	8.5	15.7	18.4	2.3	0.9
Black oak	4.0	1.8	0.6	0.3	0.2	0.7
Hickory spp.	3.0	2.0	0.8	1.2	0.6	0.7
White oak	2.4	1.6	--	--	0.7	0.9
Flowering dogwood	2.1	0.8	1.2	1.5	--	--
Pitch pine	1.8	1.2	0.3	0.3	0.0	--
E. hemlock	1.8	2.3	1.2	3.8	1.3	0.9
Yellow-poplar	1.0	1.2	0.4	4.7	1.1	1.3
Scarlet oak	1.0	0.7	--	--	0.1	0.7
Ash spp.	0.9	1.0	0.3	0.3	1.8	1.2
Striped maple	0.8	1.1	3.3	6.7	6.4	7.1
E. white pine	0.7	1.1	1.2	2.9	0.1	0.2
Black locust	0.6	0.4	--	--	0.1	0.1
Serviceberry	0.6	0.6	0.4	0.6	0.4	2.0
Yellow birch	0.6	0.5	0.6	--	0.2	0.1
Sugar maple	0.5	0.6	0.5	0.6	1.4	1.5
American beech	0.2	0.1	0.4	--	--	--
Bigtooth aspen	0.2	--	--	--	--	--
Basswood	0.2	0.2	--	--	--	--
American chestnut	0.1	0.2	0.9	1.2	0.0	0.1
E. hophornbeam	0.1	0.1	--	--	0.0	0.0
Black cherry	0.1	0.1	0.1	--	0.7	0.6
Elm spp.	0.1	0.1	--	--	3.5	--
Unk. shrub/tree	0.1	0.0	--	--	--	0.2
Virginia pine	0.0	0.0	--	--	0.0	--
Butternut	0.0	0.0	--	--	--	--
Sweetgum	0.0	--	--	--	--	--
White spruce	--	0.1	0.3	0.9	--	--
Pinus spp.	--	--	--	--	0.1	--
Azalea spp.	--	--	--	--	--	0.5
American hazelnut	--	--	--	--	--	0.2
Witch-hazel	--	0.0	--	0.3	3.2	3.8
Spicebush	--	--	--	--	0.8	1.0
Pin cherry	--	--	--	--	0.0	--
Rhododendron	--	--	--	--	3.4	3.2
Am. elderberry	--	--	--	--	0.0	--

[a] Relative frequency of live regeneration stems does not include blueberry, laurel, or Viburnum spp. counts.

Susceptibility of Oak Regeneration in Clearcuts to Defoliation by Gypsy Moth

Ray R. Hicks, Jr., Robert M. Fultineer, Barbara S. Ware, and Kurt W. Gottschalk[1]

Abstract: In 1991 and 1992, we observed gypsy moth defoliation of oak regeneration in clearcuts of varying sizes and ages. We established plots in the surrounding mature forests to document ambient gypsy moth population levels and placed subplots within the clearcuts designed to examine the effect of location relative to the clearcut edge. We found that the levels of defoliation on oak regeneration in the clearcuts closely approximated that of the adjacent mature forests. Clearcut age seemed to have little effect on rate of defoliation, but larger clearcuts (> 25 acres) had somewhat lower average defoliation, particularly in the subplots near the center. We established a more intensive sample in 3 large clearcut (> 25 acres) and found that the larvae appeared to originate from the surrounding stands.

INTRODUCTION

Harvesting is a viable silvicultural option for mature oak stands that are about to come under attack by gypsy moth (Gottschalk 1987). Heavy tree mortality is commonplace following defoliation in stands with a large proportion of oak (Hicks and Fosbroke 1987) and harvesting is one way to avoid such losses.

In addition to advoiding tree mortality due to gypsy moth, harvesting before an outbreak preserves the sprouting potential of oak stumps, thereby contributing to better oak regeneration. In the absence of sprouting, oak stands with heavy gypsy moth-induced mortality have a very low number of oak seedlings in the understory (Hix and others 1990). Clearcutting is a recommended method of regenerating oaks (USDA 1983) and has been applied to mature oak stands in the National Forests of the Appalachian region for a number of years. In addition to the benefits cited above, clearcutting may have other benefits to forests that are coming under gypsy moth attack. It has been speculated that oak seedlings are less susceptible and/or vulnerable to gypsy moth attack than mature trees. Susceptibility is a measure of the likelihood that gypsy moth will defoliate a tree or species whereas vulnerability has to do with the likelihood of damage occurring as a result of defoliation.

The basis for the speculation regarding response of seedlings versus mature trees is in part derived from casual observations (Gottschalk, 1988). Observers have noted that vegetation in clearcuts often remains green even when surrounded by mature stands that are 100% defoliated. Our study was conducted to quantify these casual observations and to determine if indeed young trees in clearcuts were less susceptible and/or vulnerable than their mature counterparts.

METHODS

Our study was conducted in the George Washington National Forest along the West Virginia-Virginia border (Figure 1). This is an area that is along the so-called leading edge of gypsy moth

---

[1] Professor, Graduate Research Assistants (Fultineer and Ware) West Virginia University and Project Leader, USDA Forest Service, Morgantown, WV.

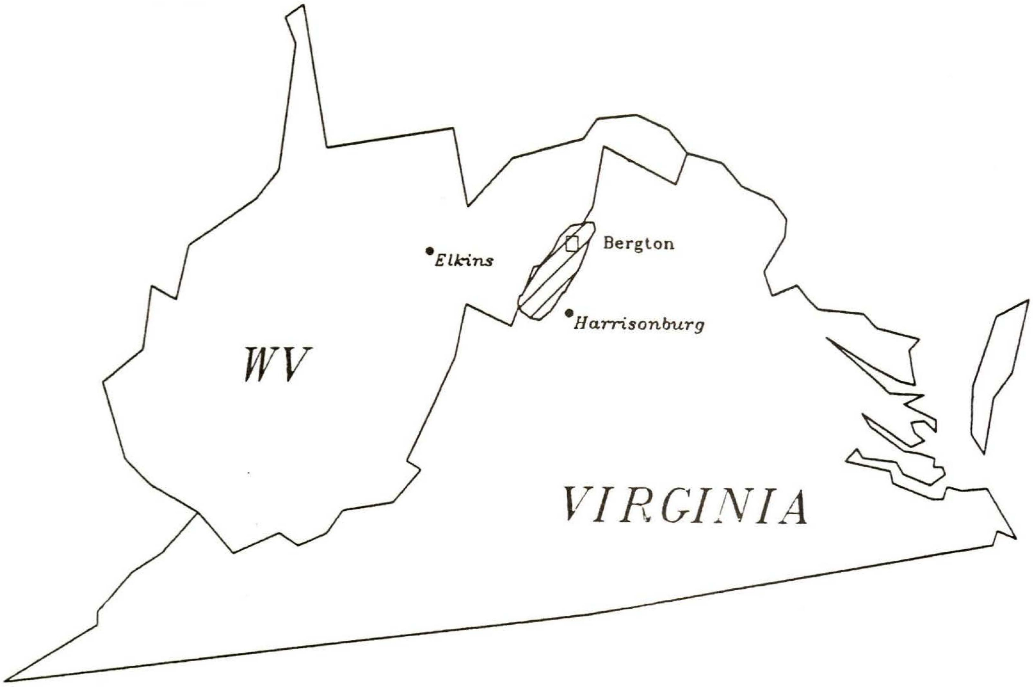


Figure 1.—Location of study area.

invasion and is in an area of predominantly oak forests (the Ridge and Valley Physiographic Province). The George Washington National Forest has conducted a number of small to medium sized clearcuts over the past decades, therefore all the ingredients needed for our study were present (oak forests, a gypsy moth population and clearcuts of varying size).

We used a heirarchial experimental design with three levels of age (time since clearcutting) and three levels of size of clearcuts. There were 5 replications within each age/size cell for a total of 45 observations in all. A diagram of the design is as follows:

		Clearcut Age		
		0-5 yrs.	5-15 yrs.	> 15 yrs.
Clearcut size	0-15 acres	5 reps	5 reps	5 reps
	15-25 acres	5 reps	5 reps	5 reps
	> 25 acres	5 reps	5 reps	5 reps

Total - 45 reps

In each clearcut, a standard sampling procedure was conducted. First, two baselines were laid out in the cardinal directions. The north-south line was installed initially and at the mid-point of this line an east-west line was installed. Four 6-ft.-radius subplots were established along each line and a subplot was placed at the intersection of the baselines for a total of 9 subplots per clearcut.

Four of the subplots were positioned 100ft. from the edge of the clearcut (outer) and four were placed equidistant from the outer subplots and the center (mid) subplot (Figure 2). The purpose of this arrangement was to examine the effect of the exterior forest on defoliation within the clearcut. It is well documented that gypsy moths disperse by "ballooning" of small first instar larvae and if the principal source of larvae in the clearcuts is from adjacent stands this should be evident in the difference between inner and outer subplots.

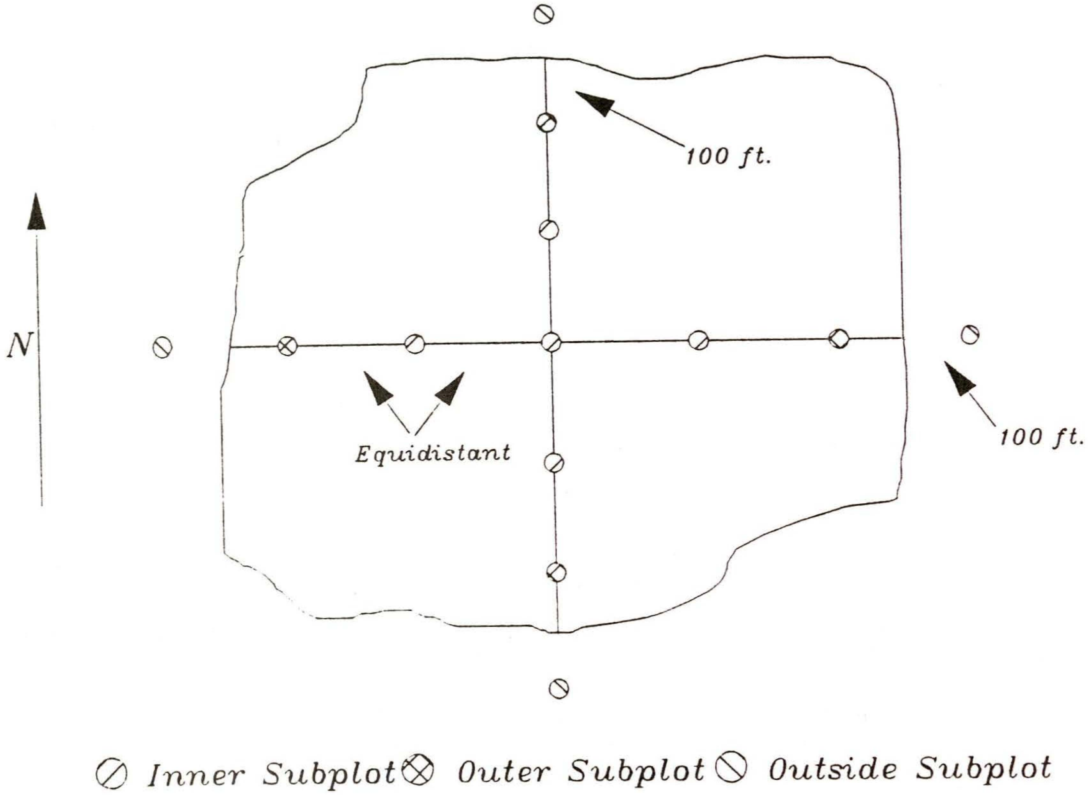


Figure 2.—Diagram of subplot positions on clearcut study areas.

The subplots were installed during May and June of 1991 and all tree seedlings were tallied by height and species. Percent ground cover was also estimated and the dominant species were listed. During the peak defoliation season (mid to late June), all clearcuts were visited in both 1991 and 1992 and percent defoliation was estimated for every tree seedling. In addition, 4 one-tenth-acre plots were established in the surrounding forest, at locations 100 ft. from the edge of the clearcuts on an extension of the baselines. These plots were used to document the ambient levels of gypsy moth in the surrounding forest and to serve as a base of comparison for the defoliation levels found within the clearcuts.

RESULTS

Although we observed defoliation of trees and seedlings of all species, it was the oaks that were most heavily defoliated and are typically among the most susceptible species in the forest (Gansner and Herrick 1985). The data reported here include only the oak defoliation results.

The general result that seems most significant, and somewhat surprising, is the fact that oak seedlings in clearcuts were generally defoliated at a level very similar to that of oaks in surrounding stands (Figs. 3 and 4). Mean oak defoliation among all subplots within clearcuts averaged 42% in 1991 while oak defoliation on surrounding stands averaged 49%. In 1992 these results were 13% and 20% respectively.

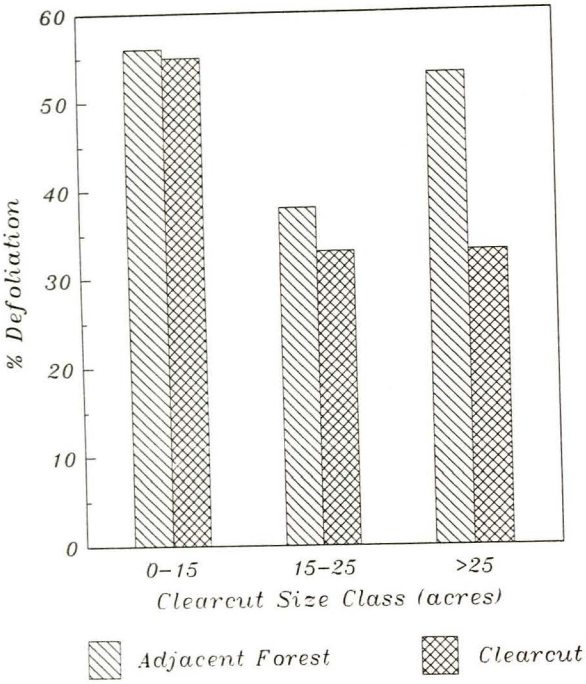
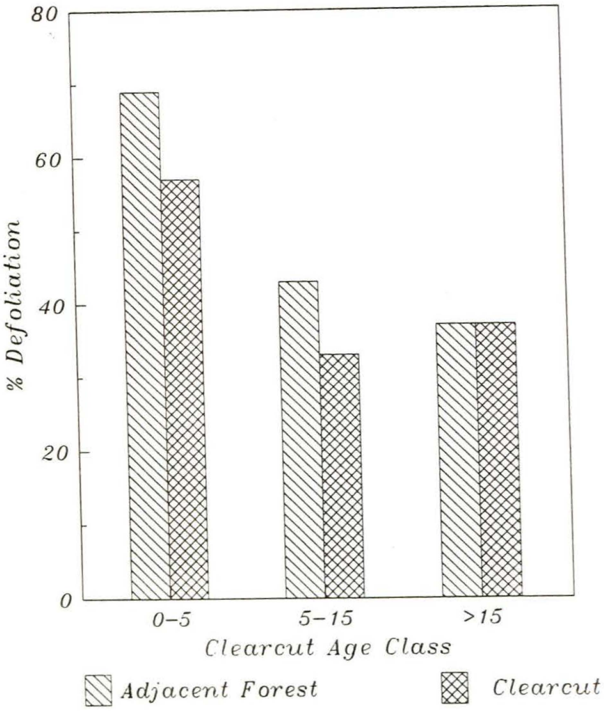


Figure 3.—Percent oak defoliation by clearcut size for 1991.

Figure 4.—Percent oak defoliation by clearcut age for 1991.



The effects of clearcut age and size were not dramatic and as yet no tests of significance have been performed on these data, but it seems unlikely that significant effects will be found. In Figure 3, it can be seen that clearcuts had a somewhat lower percentage of oak defoliation than adjacent stands and this relationship seemed to be more noticeable for larger clearcuts than for smaller ones. Logically this should be the case, particularly if the surrounding stands serve as a reservoir for caterpillars that drop into the clearcuts. The effect of clearcut age is illustrated by Figure 4, where it can be seen that younger clearcuts differed from their adjacent stands by a greater degree than older ones, and in general clearcuts had a slightly lower percentage oak defoliation than surrounding stands.

In comparing the inner versus outer subplots of clearcuts, the outer subplots had slightly higher levels of defoliation (Figure 5). But when clearcuts were selected for analysis that had 50% or greater oak defoliation in the surrounding stands (those with large resident gypsy moth populations), the difference between inner and outer subplots was greatly magnified. In Figure 5 it can be seen that outer subplots, in clearcuts where the adjacent forests were defoliated 50% or greater, had about 71% defoliation whereas inner subplots in these same clearcuts had only 52% defoliation. This is evidence affirming the hypothesis that adjacent stands serve as reservoirs for caterpillars to infest young trees in clearcuts.

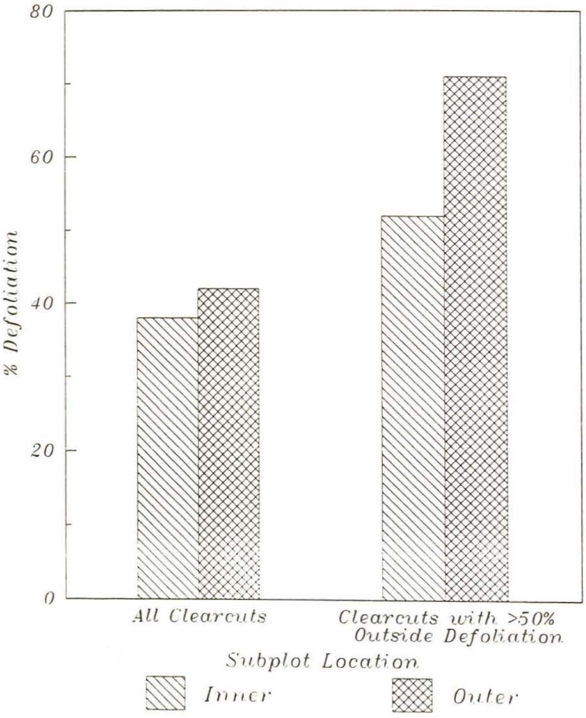


Figure 5.—Percent oak defoliation in clearcuts for inner vs. outer subplots for 1991.

In order to further investigate the effect of clearcut size on the dispersal of caterpillars into the clearcut, three larger clearcuts (> 25 acres), were selected near Bergton, Virginia (star on Figure 1). These clearcuts ranged from 30-35 acres, and age class 0-5 years old. A total of 8 transects were laid out in these clearcuts with subplots spaced equally distant from one another (Figure 6), for a total of 41 subplots for each clearcut (31 interior, 8 exterior).

During the peak defoliation season of 1991, defoliation levels along these transects and the surrounding forest were observed. Exterior forest defoliation was measured at 81.0%, while interior

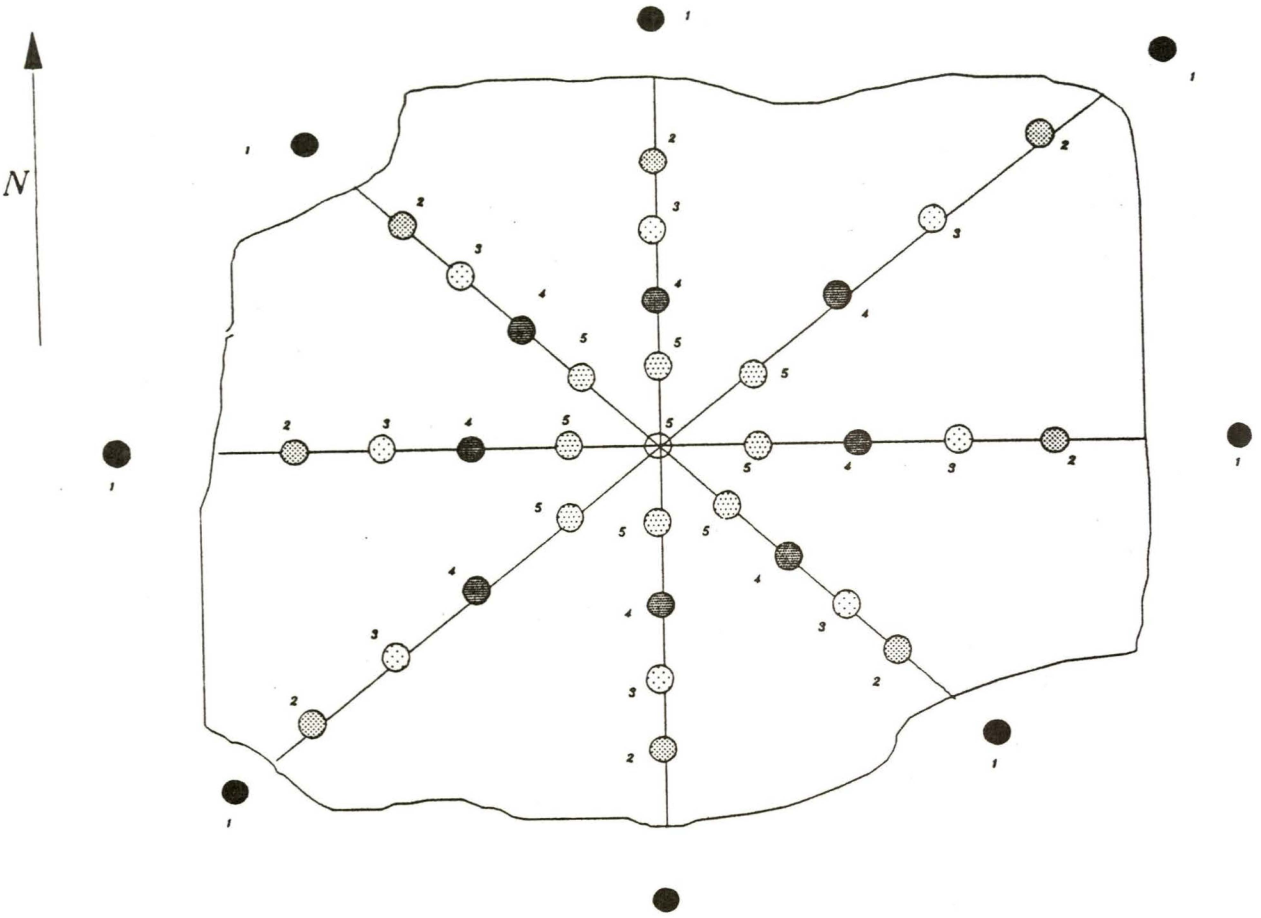


Figure 6.—Diagram of subplot positions on clearcut study area for egg mass location.

defoliation levels steadily decreased by zones (Figure 7), for an average interior rate of 41.0%. Defoliation levels for 1992 show a substantial decrease both within and outside these clearcuts indicating a gypsy moth population crash. The average exterior defoliation level decreased by 70.0% for a rate of 24.0%, while interior levels averaged 14.0% (Figure 7).

Clearcuts were also visited during March and November of 1992 to conduct egg mass counts on both interior and exterior subplots. These counts were taken in order to establish whether or not ovipositing was occurring within the cut to the same extent as they were in the surrounding forest. If so, theoretically, many defoliating larvae would have come from within the clearcut as opposed to coming from the surrounding forest.

Results of egg mass sampling in the clearcuts showed that on the average, egg mass density within the cut was generally very low, one-forth that of the exterior subplots. Data for 1990 indicate a ratio of 3:1 (exterior-310.0 E.M./acre compared to an interior average of 100.0 E.M./acre). These figures were obtained as the leading edge of gypsy moth defoliation entered the study area, while the 1991 egg mass data reflect the peak season of caterpillar activity with a ratio of 8:1 (exterior-710.0 E.M./acre compared to an interior average of 80.0 E.M./acre. Lastly, 1992 egg mass density corresponds to gypsy moth population levels with a significant decrease in density at a rate of 4:1, (exterior-370.0 E.M./acre compared to an interior average of 20.0 E.M./acre) (Figure 8).

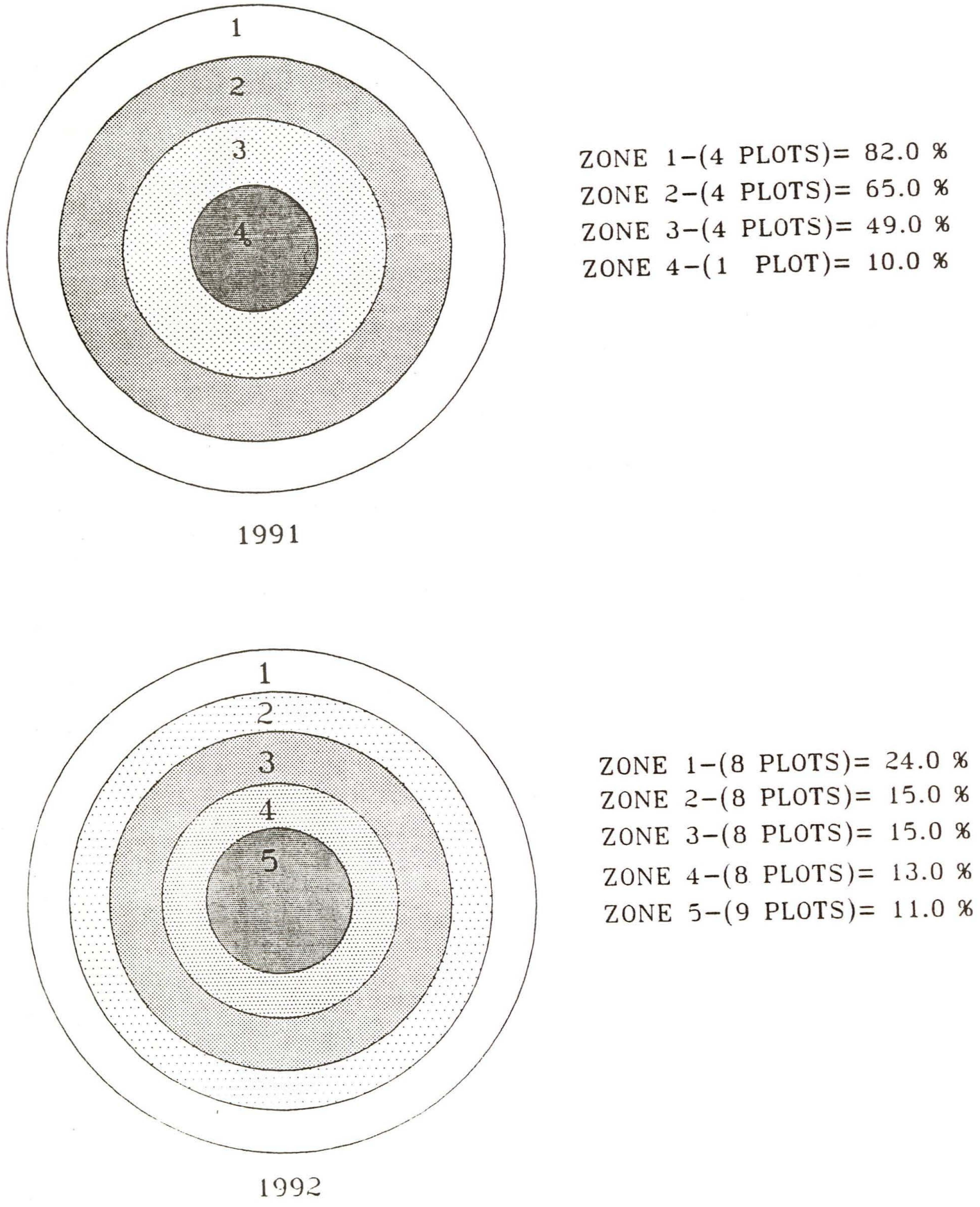


Figure 7.—Average oak defoliation by zones for three clearcuts near Bergton, VA.

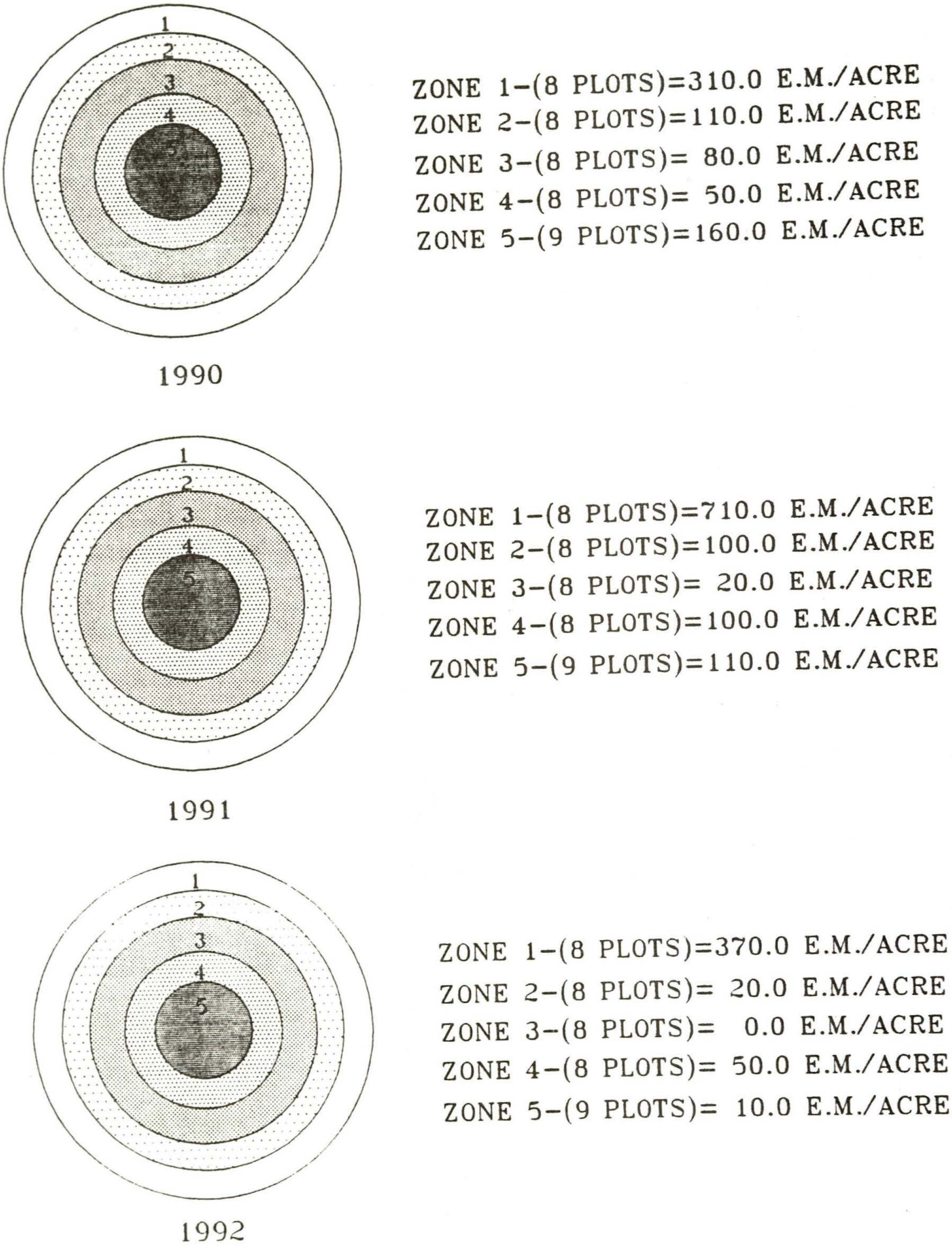

1
2
3
4
5
ZONE 1-(8 PLOTS)=310.0 E.M./ACRE
ZONE 2-(8 PLOTS)=110.0 E.M./ACRE
ZONE 3-(8 PLOTS)= 80.0 E.M./ACRE
ZONE 4-(8 PLOTS)= 50.0 E.M./ACRE
ZONE 5-(9 PLOTS)=160.0 E.M./ACRE
1990
1
2
3
4
5
ZONE 1-(8 PLOTS)=710.0 E.M./ACRE
ZONE 2-(8 PLOTS)=100.0 E.M./ACRE
ZONE 3-(8 PLOTS)= 20.0 E.M./ACRE
ZONE 4-(8 PLOTS)=100.0 E.M./ACRE
ZONE 5-(9 PLOTS)=110.0 E.M./ACRE
1991
1
2
3
4
5
ZONE 1-(8 PLOTS)=370.0 E.M./ACRE
ZONE 2-(8 PLOTS)= 20.0 E.M./ACRE
ZONE 3-(8 PLOTS)= 0.0 E.M./ACRE
ZONE 4-(8 PLOTS)= 50.0 E.M./ACRE
ZONE 5-(9 PLOTS)= 10.0 E.M./ACRE
1992

Figure 8.—Average egg mass density by zones for three clearcuts near Bergton, VA.

An assessment has not been conducted on the relationship of gypsy moth population to the host foliage biomass present. For example, mature oak forest probably contain substantially more oak foliage biomass than do clearcuts. As Figure 9 indicates, egg mass location appears to be a function of the population density. During the peak season, 1991, exterior and interior subplots both exhibited proportionately higher levels of egg masses on woody stems present. By 1992, egg mass concentrations on all substrates began decreasing due to the apparent crash of the gypsy moth population.

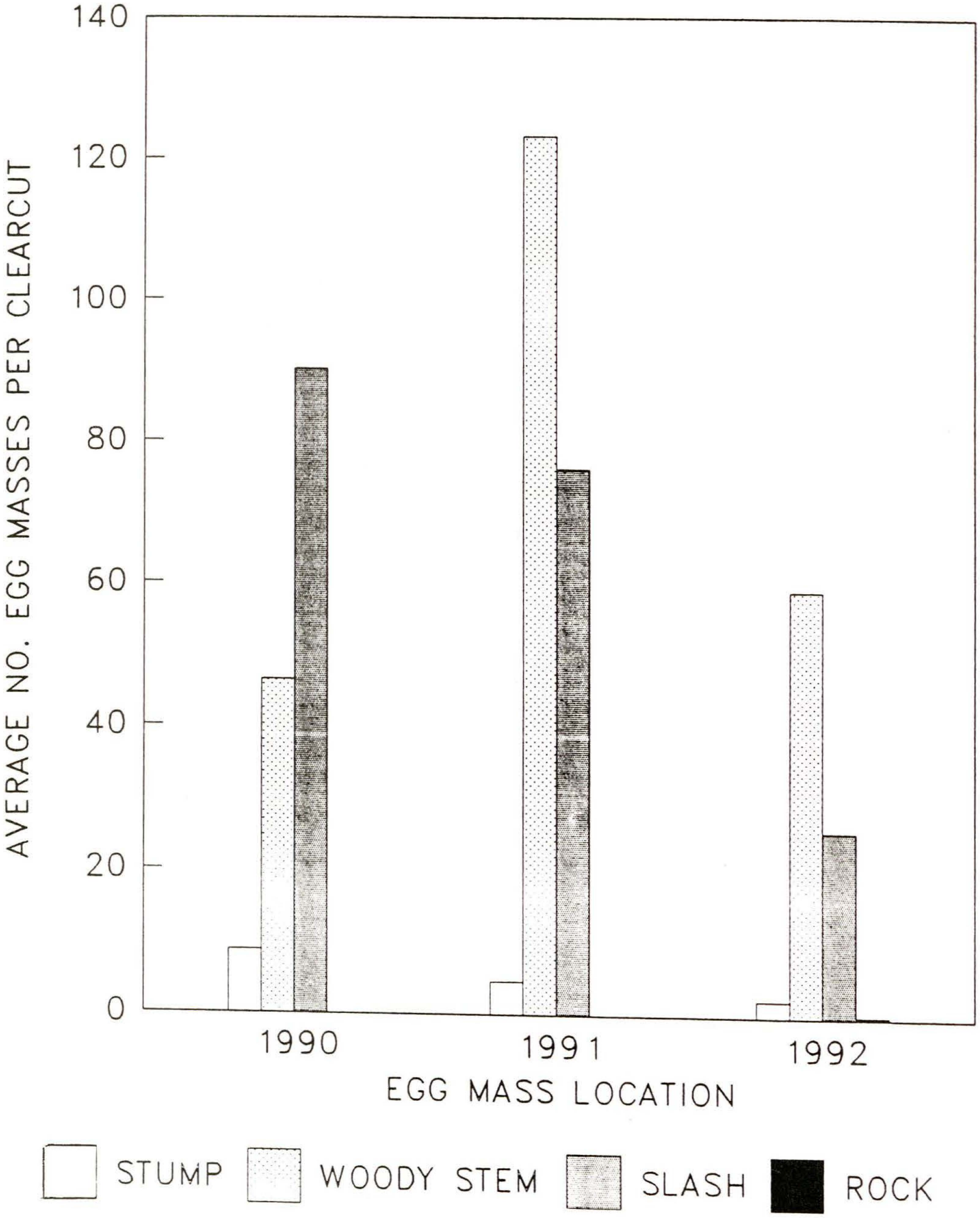


Figure 9.—Location of egg masses by years for cleatcuts

DISCUSSION

Our data indicate that oak seedlings in clearcuts are indeed susceptible to defoliation by gypsy moth and are defoliated to a degree that closely resembles that of adjacent surrounding forests. However, the facts that larger clearcuts had comparatively lower defoliation than small ones and that outer subplots in clearcuts had higher defoliation than interior ones suggest that many caterpillars are entering clearcuts from adjacent stands. This suggestion was born out when we looked both at the distribution of defoliation and egg masses in larger clearcuts, where we found higher levels of defoliation and higher egg mass densities around the periphery of large clearcuts as compared to the inner subplots. An implication of this result is that larger clearings might insulate oaks in the interior from gypsy moth defoliation. Our examination of larger clearcuts near Bergton, Virginia seems to bear this out.

The question of why casual observations find clearcuts to be undefoliated even when surrounded by heavily defoliated forests can be answered based upon the species composition of the clearcuts versus the surrounding forest. In our study, we found that 76% of the tree seedlings in clearcuts were non-oaks such as red maple. In the surrounding forests the ratio was almost exactly reversed with 75% of the trees being the highly preferred oak species.

Clearcutting of mature oak stands about to come under gypsy moth attack may have several advantages such as presalvaging anticipated losses, retaining oak sprouting potential and reducing food available for gypsy moth. But, oak seedlings do not appear to have any intrinsic resistance to gypsy moth defoliation as compared to older trees. The question of vulnerability of young oaks in clearcuts is as yet unanswered. We will continue to monitor the oak seedlings in these same clearcuts and document their defoliation, growth and mortality levels as compared to similar data collected from adjacent surrounding forests.

ACKNOWLEDGMENTS

We wish to acknowledge the technical assistance of Mr. David E. Fosbroke and Mr. John Flesher. We also wish to acknowledge the assistance in data management of Dr. Edwin Townsend College of Agriculture and Forestry, West Virginia University. Funding for this study was provided to West Virginia University from the USDA Forest Service, Northeast Forest Experiment Station. This is West Virginia Agriculture and Forestry Experiment Station Scientific Paper No. 2397.

LITERATURE CITED

Gansner, D. A. and Herrick, O. W. 1985. Host preference of gypsy moth on a new frontier of infestation. USDA, Forest Serv. Res. Note NE-330. 3p.

Gottschalk, K. W. 1987. Prevention: The silvicultural alternative. (in Coping With the Gypsy Moth in the New Frontier, Hicks, R. R., Jr. and Fosbroke, S. eds.) Morgantown, WV. pp. 92-104.

Gottschalk, K. W. 1988. Gypsy moth and regenerating Appalachian hardwood stands. (In: Proc. Guidelines for Regenerating Appalachian Hardwood Stands) Morgantown, WV. 241-254.

Hicks, R. R., Jr. and Fosbroke, D. E. 1987. Mortality following gypsy moth defoliation in the central Appalachians. Proc. Sixth Cent. Hardwood Conf., Knoxville, TN. 423-426.

Hix, D. M., Fosbroke, D. E. and Hicks, R. R., Jr. 1990. Effects of gypsy moth defoliation on regeneration of Appalachian Plateau and Ridge and Valley stands. Proc. 1990 Soc. Am. Foresters Conv. Washington, D.C.

USDA, Forest Serv. 1983. Silvicultural Systems for the Major Forest Types of the United States. USDA, FS Ag. Handbook 445. 191pp.

Predictability of Gypsy Moth Defoliation in Central Hardwoods: A Validation Study[1,2]

David E. Fosbroke[3] and Ray R. Hicks, Jr.[4]

Abstract: A model for predicting gypsy moth defoliation in central hardwood forests based on stand characteristics was evaluated following a 5-year outbreak in Pennsylvania and Maryland. Study area stand characteristics were similar to those of the areas used to develop the model. Comparisons are made between model predictive capability in two physiographic provinces. The tested model was inconsistent in its predictive capacity. In the Ridge and Valley province of Maryland, model predictions overestimated actual stand level defoliation. In the Appalachian Plateau of Pennsylvania, the same model underestimated stand level defoliation. The stand-based model evaluated in this study does not provide forest managers with a satisfactory method for predicting the actual amount of defoliation in a given stand. However, the model appears to be useful for estimating the relative amount of defoliation to be expected in different stands.

WHY PREDICT DEFOLIATION?

Numerous papers have described the devastating effects of gypsy moth (Lymantriidae: *Lymantria dispar* (L.)) defoliation on eastern and central hardwood forests, especially those comprised of the highly favored oak species (Kegg 1973; Campbell and Sloan 1977; Gansner and Herrick 1979; Stephens 1988; Fosbroke and Hicks 1989; Twery 1990). To limit these damages, forest managers must make decisions on the type and timing of treatments to be applied to the forests in their jurisdiction. Common sense dictates that treatment efforts be initiated in high value stands that are likely to suffer unacceptable levels of damage if defoliated. The hazard rating system outlined by Mason et al. (1986) provides a framework for setting treatment priorities. Prediction of defoliation is an important component of this hazard rating system.

PREDICTING DEFOLIATION

Many factors influence the ability of a tree or a forest stand to survive insect attack. Prime among them are the severity of attack and the number of attacks sustained during an outbreak. Individual trees, tree species and forest stands have different probabilities of being defoliated during an

---

[1] Published with the approval of the Director of the West Virginia University Agricultural and Forestry Experiment Station as Scientific Article No. 2399. This research was partially funded by the U.S.D.A. Forest Service, Northeastern Forest Experiment Station, under Cooperative Agreement 23-248.

[2] The authors thank Dr. Maryann Fajvan, Dr. Harry V. Wiant, Jr., Dr. Linda Butler, Mrs. Sandra L. C. Fosbroke, and Mr. John R. Myers for their comments on earlier drafts of this manuscript. The authors accept responsibility for any errors or omissions.

[3] Formerly Research Assistant, Division of Forestry, West Virginia University. Currently Statistician at the National Institute for Occupational Safety and Health, 944 Chestnut Ridge Road, Morgantown, WV 26505.

[4] Professor of Forest Ecology, Division of Forestry, West Virginia University, P.O. Box 6125, Morgantown, WV 26506.

outbreak. This likelihood of defoliation, termed susceptibility, is a function of the acceptability of the plant host to the defoliator and its suitability for insect growth and development. For the gypsy moth, this involves complex interactions between larvae and host foliage (Hodkinson and Hughes 1982; Kleiner et al. 1989; Barbosa 1978). The acceptability of plant species to gypsy moth larvae has been evaluated since the late 1800's when Forbush and Fernald (1896) evaluated 477 species of trees, shrubs and plants. Subsequent work by Mosher (1915) remains the classic reference for placing plant species into gypsy moth food preference classes. These classes have been condensed by Houston and Valentine (1985) and Montgomery (1990). Recently, the suitability of several southern and western species as gypsy moth hosts has been evaluated (Miller and Hanson 1989; Barbosa et al. 1983; Witter et al. 1990; Berisford and Montgomery 1990).

Setting treatment priorities before gypsy moth infestation involves assessment of susceptibility at the stand level. Since some plant species are more susceptible than others, it should be possible to predict stand defoliation based on species composition. A variety of techniques have been used to develop such defoliation prediction models (Table 1). Though considerable effort has gone into the development of these models, their usefulness has generally not been extensively evaluated. One test of the usefulness of a model is to apply the model to a new set of conditions and compare the predicted outcome with the actual amount of defoliation occurring in the forest stand. This paper describes the results of this type of validation for one gypsy moth defoliation prediction model selected from the literature.

Table 1.—Published equations for the prediction of stand level defoliation

Study	**Prediction variables**	**Equation form**
Campbell and Standaert (1974)	Egg Mass Density Preferred Food Density Prior Defoliation Total Foliage Available	Multiple Regression
Gansner et al. (1985)	Egg Mass Density	Non-linear Regression
Herrick and Gansner (1986)	Basal Area of Oak Basal Area of Black and Chestnut Oak Basal Area of Trees w/ Good Crowns Mean Stand Diameter	Classification Tree (AID)
Valentine and Houston (1979)	Σ Diameter Preferred Host Σ Basal Area Preferred Host Σ Diameter Preferred Host w/ more than 1 Deep Fissure Σ Diameter Preferred Host w/ more than 1 Bark Flap Quadratic Mean Diameter of Preferred Host	Discriminant Analysis
Valentine and Houston (1984)	Σ Diameter Preferred Host Σ Basal Area Preferred Host Analysis Quadradic Mean Diameter of Preferred Host	Discriminant

Though it would be desirable to evaluate each model available from the literature, models that incorporate gypsy moth population parameters were not evaluated. The reasons for this are two-fold: first, gypsy moth population parameters were known for only a small sample of our study sites; second, the authors feel that proper planning of gypsy moth treatments requires estimating defoliation potential long before gypsy moth life stages build up within a stand. To even consider the full range of silvicultural options outlined in Gottschalk's (1987, 1993) guidelines requires making plans at least three years before defoliation is expected. For these reasons, the models which could be evaluated were the Automatic Interaction Detection (AID) model published by Herrick and Gansner (1986) and the Discriminant model published by Valentine and Houston (1984). Since study site stand characteristics were not within the standard deviations published in the Valentine and Houston paper, the discrimenant model was also eliminated from the analyses. Therefore, the AID model published by Herrick and Gansner was the model selected to be evaluated.

THE AID MODEL

Herrick and Gansner (1986) developed a defoliation prediction model from data collected on approximately 600 plots established between Carlisle and State College, Pennsylvania in 1978. Defoliation levels were variable from 1979 through 1983. Defoliation was most widespread in these central Pennsylvania study sites in 1981 when forty-seven percent of the plots received at least 30 percent defoliation. Pre-defoliation stand conditions for the data used to develop the model are shown in Table 2.

Table 2.—Selected plot variables describing pre-defoliation stand conditions in the central Pennsylvania plots used by Herrick and Gansner to develop the AID defoliation model[1]

Variable	Mean	Range
Dbh	7.4	3.9-13.4
Trees/acre	255	80-650
BA/Acre	90	15-190
Stocking	81	20-158
% BA in oak	68	0-100
Avg NRO SI	61	25-100
Stand age	71	15-175

[1] Source: Herrick and Gansner (1986).

Herrick and Gansner used Automatic Interaction Detection (AID), a statistical tree classification technique, for determining the "best predictors" of stand defoliation. The AID technique divides a sample in a series of two-way splits into subgroups. At each split, the chosen predictor variable forms two new groups so that the reduction in the variance of the dependent variable is maximized. In the Herrick and Gansner model, the dependent (i.e. outcome) variable is termed defoliation potential, a value equivalent to a 3-year average percent defoliation. Predictor variables selected by the AID technique are the percent basal area in oak, the percent basal area in black and chestnut oak, the percent basal area in trees with good crowns, and the average stand diameter in inches. Figure 1 is the dendrogram used by Herrick and Ganser (1986) to show their results.

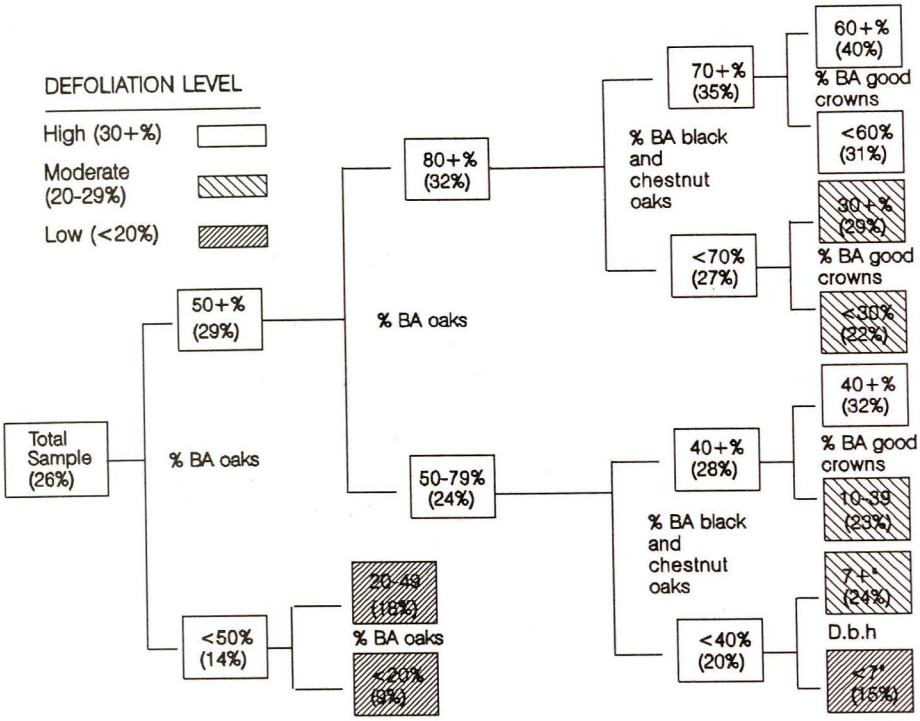

DEFOLIATION LEVEL
High (30+%)
Moderate (20-29%)
Low (<20%)
Total Sample (26%)
% BA oaks
50+% (29%)
% BA oaks
80+% (32%)
% BA black and chestnut oaks
70+% (35%)
60+% (40%)
% BA good crowns
<60% (31%)
<70% (27%)
30+% (29%)
% BA good crowns
<30% (22%)
50-79% (24%)
% BA black and chestnut oaks
40+% (28%)
40+% (32%)
% BA good crowns
10-39 (23%)
<40% (20%)
7+" (24%)
D.b.h
<7" (15%)
<50% (14%)
20-49 (18%)
% BA oaks
<20% (9%)

Figure 1.—Guide for estimating gypsy moth defoliation potential. Adapted from Herrick and Gansner (1986).

THE WVU GYPSY MOTH PLOTS

The AID prediction model described above was applied to data from 0.10-acre plots established in the Appalachian Plateau physiographic province of western Pennsylvania and the Ridge and Valley province of western Maryland. The plots were established between 1984 and 1986 as a part of a cooperative research agreement between West Virginia University and the U.S.D.A. Forest Service. Specifics about plot establishment and gypsy moth impacts in these study areas are detailed elsewhere (Hix et al. 1991, Fosbroke and Hicks 1989, Crow and Hicks 1990). Since these study plots were located in two different physiographic provinces, comparisons between defoliation predicted by the AID model and actual defoliation were made separately for the Pennsylvania and the Maryland data sets.

From 1985 through 1989, each tree on the WVU study plots was revisited when defoliation was at its peak (late June-early July). Ocular estimates of defoliation were made for each tree by two crew members. These two ocular estimates were averaged to obtain an individual tree defoliation level (ITDL). A weighted average plot defoliation level (WAPDL) was calculated for each plot using the method of Gansner and Herrick (1985), where ITDL values were weighted by the tree's diameter. These weighted ITDL estimates were than averaged over the plot producing the WAPDL. The resulting estimate represents the proportion of the plot that would appear to be defoliated if viewed from an airplane.

Initial Stand Conditions - Appalachian Plateau Province

Prior to defoliation in 1985, the Appalachian Plateau study sites were primarily in fully-stocked, mixed-oak stands that averaged 236 trees/acre and 107 square feet of basal area/acre. Table 3 compares pre-defoliation stand conditions of defoliated plots— those with a WAPDL greater than 30 percent in one or more years— with non-defoliated plots— those that never had a WAPDL exceeding 30 percent. Defoliated plots had a significantly (two-tailed t-test) greater level of stocking, larger oak component, and older stand age than did the non-defoliated plots when the study began. There was no significant difference in the average stand diameter, site quality (n. red oak site index), number of trees/acre, basal area/acre or volume/acre between defoliated and non-defoliated plots. Thirty percent of the trees in non-defoliated plots were species in Mosher's (1915) preferred food class compared to 55 percent of the trees in defoliated plots. Non-defoliated plots had a higher maple component than defoliated study areas, mostly due to an abundance of sugar maple. The difference in oak composition already noted is due to the increased proportion of chestnut oak, white oak, and northern red oak in the defoliated plots.

Table 3.—A comparison of stand conditions prior to defoliation between defoliated and non-defoliated plots in the Appalachian Plateau[1]

	Defoliated			Non-defoliated		
Variable	**N**	**Mean**	**Std**	**N**	**Mean**	**Std**
Dbh	157	8.13[a]	1.50	70	7.80[a]	1.45
Trees/acre	157	234.20[b]	65.29	70	239.57[b]	70.86
BA/acre	157	109.11[c]	35.84	70	102.12[c]	39.80
Stocking	157	80.47	19.54	70	72.52	24.59
Vol/acre	148	8438.06[d]	5758.63	67	6947.24[d]	4820.43
% BA in oak	157	79.82	16.19	70	47.43	31.09
% Trees in oak	157	53.78	24.39	70	27.18	24.22
Avg NRO SI	156	55.28[e]	8.31	60	60.04[e]	11.57
Stand age	156	78.80	17.63	69	74.28	17.94

[1] Comparisons based on two-tailed t-test.

Initial Stand Conditions - Ridge and Valley Province

As in the Appalachian Plateau, study sites were located in fully-stocked, mixed-oak stands. Prior to defoliation in 1985, Ridge and Valley stands averaged 238 trees/acre and 102 square feet of basal area per acre. Defoliated plots began with significantly (two-tailed t-test) more trees/acre, greater stocking, higher n. red oak site index, greater proportion of oak, and smaller stand diameters than non-defoliated plots (Table 4). There was no significant difference between defoliated and non-defoliated areas in the basal area/acre, average stand age, or sawtimber volume. There was little difference in the proportion of the stand that was made up of trees from Mosher's (1915) prefered food group. In fact, non-defoliated plots in the Ridge and Valley had more favored trees than did defoliated plots. Though both defoliated and non-defoliated plots averaged 85-91 percent of their basal area in oak (Table 4), the relative contribution of the five oak species to the overall stand composition was different in defoliated and non-defoliated plots. In defoliated plots, nearly 60 percent of the stand composition consisted of chestnut oak while white oak made up 10 percent of the stand and n. red oak was nearly non-existent. In contrast, white oak made up nearly 30 percent of the non-defoliated plots, followed by chestnut oak (21%) and n. red oak (11%). Though individual species of pine varied, both defoliated and non-defoliated plots averaged 7 to 8 percent conifer species. In contrast with the Appalachian Plateau, maple was a small component of all Ridge and Valley stands and hickory represented 7 to 8 percent of Ridge and Valley stands.

Table 4.—A comparison of stand conditions prior to defoliation between defoliated and non-defoliated plots in the Ridge and Valley[1]

	Defoliated			Non-defoliated		
Variable	**N**	**Mean**	**Std**	**N**	**Mean**	**Std**
Dbh	67	8.09	1.35	91	8.72	1.58
Trees/acre	67	265.20	76.80	91	218.02	74.84
BA/acre	67	102.53^a	17.95	91	100.83^a	22.87
Stocking	67	90.96	14.78	91	81.76	16.67
Vol/acre	65	6663.07^b	4418.47	88	8069.62^b	4453.93
% BA in oak	67	91.01	10.63	91	85.36	20.51
% Trees in oak	67	82.21	15.03	91	74.33	22.15
Avg NRO SI	63	58.01	7.52	79	55.83	8.17
Stand age	63	73.90^c	14.18	79	77.47^c	15.18

[1] Comparisons based on two-tailed t-test.

Stand Level Defoliation - Appalachian Plateau

Defoliation was spotty in the Appalachian Plateau, being concentrated in some stands and absent in others (Table 5). The Pennsylvania plots received the most defoliation in 1985 and 1986 (Tables 5 and 6), averaging over 50 percent in the defoliated plots (Table 5). By 1988, the gypsy moth population had declined and the average plot defoliation was less than 10 percent (Table 6). Nine stands were heavily defoliated (WAPDL ≥50%) in 1985 and/or 1986 (Table 5). Six stands received moderate levels of defoliation (30% ≤ WAPDL < 50%) in one or both of those years. One stand was moderately defoliated in 1987. The remaining two stands recieved essentially no defoliation during the study. Only one stand received three years of moderate or heavy defoliation while seven stands had at least 2 years of moderate defoliation or greater.

Table 5.—Defoliation history of Appalachian Plateau stands in southwestern Pennsylvania[1]

Stand #	**1**	**3**	**4**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**14**	**15**	**16**	**25**	**26**	**27**	**28**	**29**
# Plots	**8**	**8**	**11**	**29**	**16**	**7**	**5**	**7**	**5**	**6**	**12**	**10**	**14**	**5**	**25**	**13**	**8**	**5**
	- - - - - - - - - - - - - - - - - - Average defoliation (Percent)[2] - - - - - - - - - - - - - - - - - -																	
Year																		
1985	48	0	33	34	50	7	39	31	24	*	*	1	100	*	*	*	*	*
1986	5	57	41	80	45	16	40	48	28	31	93	6	12	75	52	35	54	65
1987	15	10	7	17	17	3	12	30	30	42	33	0	43	17	13	31	11	21
1988	2	4	11	3	13	1	3	11	10	14	23	0	15	4	7	9	3	13
1989	11	12	7	8	13	6	10	10	10	11	7	0	5	12	6	10	8	10
85&86	27	52	37	74	46	12	39	40	26	31	93	4	56	75	52	35	55	65
85-89	17	21	21	34	26	8	23	27	20	25	39	6	37	27	20	21	21	27

[1] Average of the weighted average plot defoliation level (WAPDL) of all plots in the stand. Each stand may contain both defoliated and non-defoliated plots.

[2] Study areas that were established after defoliation in 1985 and before defoliation in 1986 are indicated with an "*".

Table 6.—Comparison of annual defoliation levels in defoliated and non-defoliated plots in the Appalachian Plateau study areas[1]

	Nondefoliated plots		**Defoliated plots**		**All plots**	
Year	**(%)**	**(N)**	**(%)**	**(N)**	**(%)**	**(N)**
1985	4.35	(60)	55.51	(62)	30.34	(122)
1986	11.65	(37)	55.82	(157)	47.39	(194)
1987	3.71	(37)	23.01	(157)	19.33	(194)
1988	2.94	(37)	9.51	(157)	8.25	(194)
1989	6.73	(37)	9.55	(155)	9.01	(192)
85&86	10.26	(37)	58.90	(157)	49.62	(194)
85-89	7.21	(52)	28.83	(157)	23.45	(209)

[1] A plot was considered defoliated if the weighted average plot defoliation level exceeded 30 percent in at least one year.

Stand Level Defoliation - Ridge and Valley

Defoliation was less severe in the Ridge and Valley plots located in western Maryland than in the Appalachian Plateau of southwestern Pennsylvania (Tables 7 and 8). Defoliation peaked in 1985 with an average over all plots of nearly 30 percent (Table 7). A year later, defoliation had declined to under 5 percent. Defoliation was greatest in stands F, G, J, K, L, and M (Table 8). Stands N and P were maintained as controls through the application of Dimilin. Stand M was clearcut in the spring of 1986 following heavy defoliation because of its high value. The remaining stand, stand I, received only a single light defoliation. Though this stand was excluded from a spray block in 1986, shortly following Dimilin application in an adjacent spray block, larval populations declined and active defoliation ceased.

Table 7.—Defoliation history of Ridge and Valley stands in western Maryland[1]

Stand	**F**	**G**	**I**	**J**	**K**	**L**	**M[2]**	**N**	**P**	**Q**
# Plots	**26**	**8**	**30**	**13**	**7**	**13**	**17**	**16**	**9**	**37**
Year	- - - - - - - - - - - - - - - Average Defoliation (Percent) - - - - - - - - - - - - - -									
1985	52	35	3	67	49	51	-	10	<1	0
1986	1	0	17[3]	0	0	0		0	0	0
1987	5	3	<1	0	3	0		0	0	0
1988	1	0	1	0	0	0		1	0	16
1989	<1	<1	<1	0	0	0		1	0	4
85-89	23	19	8	35	24	38		8	2	15

[1] Average of the weighted average plot defoliation level (WAPDL) of all plots in the stand. Each stand may contain both defoliated and non-defoliated plots.

[2] Stand M was clearcut in the spring of 1986 in a salvage operation. These plots are not included in Table 8.

[3] Larval activity and defoliation ceased in mid-season in 1986 in stand I.

Table 8.—Comparison of annual defoliation levels in defoliated and non-defoliated plots in the Ridge and Valley study areas[1]

	Nondefoliated plots		**Defoliated plots**		**All plots**	
Year	**(%)**	**(N)**	**(%)**	**(N)**	**(%)**	**(N)**
1985	5.24	(75)	54.62	(62)	27.58	(137)
1986	4.62	(91)	1.38	(67)	3.24	(158)
1987	0.64	(90)	2.08	(67)	1.25	(157)
1988	1.51	(91)	9.67	(66)	4.94	(157)
1989	1.93	(91)	0.28	(67)	1.24	(158)
85&86	4.47	(91)	25.96	(67)	13.58	(158)
85-89	6.85	(83)	32.80	(67)	18.44	(150)

[1] Average of the weighted average plot defoliation level (WAPDL) of all plots in the stand. Each stand may contain both defoliated and non-defoliated plots.

AID Model Estimates - Appalachian Plateau

Figure 2 shows the 3-year defoliation level predicted by the Herrick and Gansner guide (line) and the actual defoliation for each of the 184 plots used from the Appa-lachian Plateau data set (points).[5] The x-axis represents a counting of plots (observations) from plot n=1 to plot n=184. The model under-estimates the 3-year average percent defol-iation for those plots which had actual defol-iation levels shown above the line.

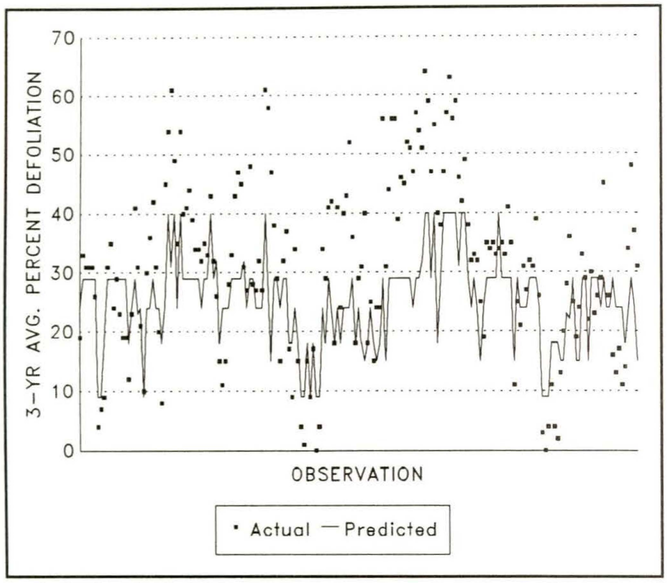


Figure 2.—Comparison of 3-year average defoliation levels predicted using the Herrick and Gansner (1986(AID model and actual 3-year average defoliation in the Appalachian Plateau plots (N=184).

In general, the model underestimated the amount of defoliation in these Pennsylvania plots. The mean predicted value for the 184 plots tested was 25.3 percent compared with an actual value of 31.4 percent. Predicted defoliation was compared to actual defoliation using a paired t-test. The resulting t-value of 4.99 with 183 degrees of freedom was significant (p=0.0001). Table 9 provides sample statistics for both predicted and actual defoliation levels.

Table 9.—Sample statistics of actual and predicted defoliation (percent) from the Appalachian Plateau study plots

	Predicted	**Actual**
Number of plots	184.0	184.0
Mean	25.3	31.4
Median	25.3	29.0
Minimum	9.0	0.0
Maximum	40.0	64.0
Standard deviation	7.4	14.6

---

[5] The Pennsylvania data set contained 227 plots. Forty-three were eliminated from the analysis because they were not revisited following establishment in 1985 (33 plots) or because they were planned as sprayed control plots and received no defoliation.

Seventy-eight of the 184 plots (42%) were correctly classified into the low (< 20%), moderate (20-29%), and high (>30%) defoliation categories used by Herrick and Gansner. Thirty-one of the 45 plots (68%) predicted to be in the low defoliation category had less than 20 percent defoliation during the 3 years. Twenty-seven of the 118 plots (23%) predicted to have moderate defoliation had 20 to 29 percent defoliation on average. Nearly all (20 of 21) of the plots predicted to receive high levels of defoliation did. Sixty-eight percent (80/118) of the plots expected to be in the moderate defoliation category were actually in the high defoliation category. No plot was predicted to exceed 40 percent defoliation over the 3 years, however 47 plots (27%) experienced greater than 40 percent defoliation with a maximum 3-year average defoliation of 64 percent. The data were grouped into Herrick and Gansner's three categories for a chi-square goodness of fit test. The test with 4 degrees of freedom had a significant chi-square value of 81.74, indicating that predicted defoliation levels did not reflect actual defoliation.

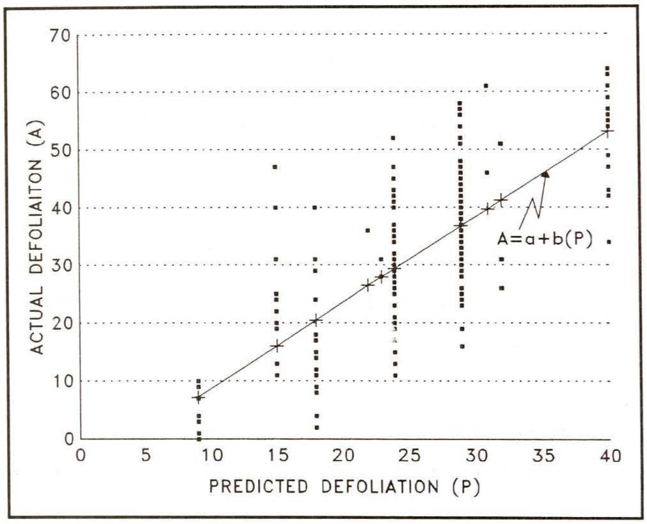


Figure 3.—Regression of 3-year defoliation levels to predicted defoliation levels using Herrick and Gansner model.

The predicted levels of defoliation from the Herrick and Gansner model were positively correlated to actual defoliation levels over a three-year period (r=0.75). The pattern of actual defoliation shown in Figure 2 reflects the pattern of predicted defoliation indicated by the line. The highest actual values of defoliation were generally on those plots that had the highest predicted values. Where predicted values are low, the actual values also tended to be low. A simple linear regression of actual to predicted defoliation is shown in Figure 3. An ideal relationship would yield an intercept of 0 and a slope of 1. Additionally, the sum of the squared residuals would approach 0. The equation— A = -6.160914 + 1.481787 (P) —describes the regression line in Figure 3. The r^2 for this line is 0.57. The student's t-test for the intercept (H_o: a=0) and the slope (H_o: b=1) were significant with t-values of -2.43 (p=0.0162) and 5.008 (p=0.0000) respectively.

AID Model Estimates - Ridge and Valley

Sixty-seven plots were used to evaluate the usefulness of the Herrick and Gansner guide for predicting gypsy moth defoliation in the Ridge and Valley province of western Maryland.[6] There was no known application of insecticide in any of these plots; however, no plot received significant defoliation for more than one year. Figure 4 is a plot of the predicted 3-year average defoliation for each plot using the Herrick and Gansner guide (line) and of the actual defoliation level that these plots averaged from 1985-1987 (points).

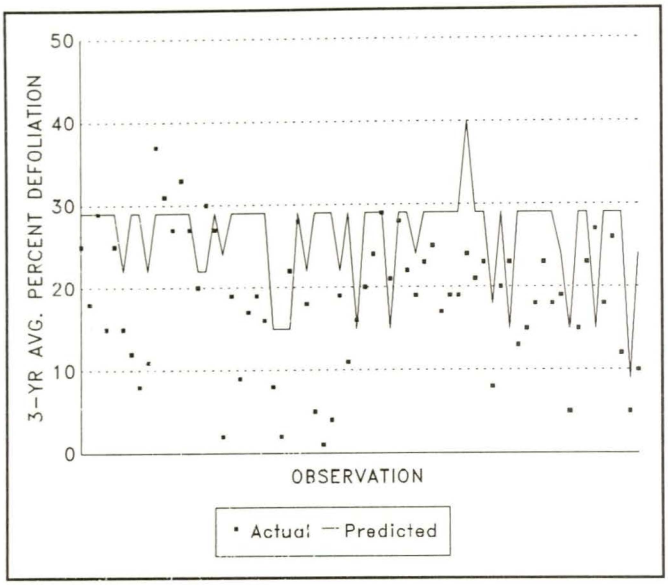


Figure 4.—Comparison of 3-year average defoliation levels predicted using the Herrick and Gansner (1986) AID model and actual 3-year average defoliation in the Ridge and Valley study plots (N=67).

In general, the model overestimated the amount of defoliation in these Maryland plots. The mean predicted defoliation level of the 67 plots was 26.1 percent compared with an actual defoliation value of 18.5 percent. A comparison of actual to predicted defoliation resulted in a t-value of -7.48 with 66 degrees of freedom. Table 10 provides sample statistics for both predicted and actual defoliation levels.

The three-year defoliation level was correctly predicted for 26 (39%) of these plots. In only 9 plots was the prediction an underestimate of the actual defoliation level. The remaining 32 plots had actual defoliation levels that were lower for the three-year period than predicted by the guide. Thirty-one of the 56 plots (55%) which were predicted to have a moderate 3-year average defoliation level actually had less than 20 percent average defoliation over the period. These data were also grouped into Herrick and Gansner's three categories for a chi-square goodness of fit test. The test with 4 degrees of freedom had a nonsignificant chi-square value of 2.484, indicating that predicted defoliation levels did reflect actual defoliation categories. Note that the 3x3 contingency table had 6 cells with expected values of less than 5. The contrast between the results in the Appalachian Plateau and in the Ridge and Valley is evident by comparing Figures 2 and 4. In general, the model underestimates defoliation in the Appalachian Plateau sites, it overestimates defoliation in the Ridge and Valley sites.

---

[6] The Maryland data set contained 158 plots. Ninety-two plots were eliminated from the analysis because they were planned as sprayed controls (25 plots), appeared to have been affected by adjacent spray blocks (30 plots), or did not receive defoliation until 1988 (37 plots).

Table 10.—Sample statistics of actual and predicted defoliation from the Ridge and Valley study plots.

	Predicted	Actual
Number of plots	67.0	67.0
Mean	26.1	18.5
Median	29.0	19.0
Minimum	9.0	1.0
Maximum	40.0	37.0
Standard deviation	5.6	8.1

The predicted levels of defoliation from the Herrick and Gansner model had a weakly positive correlation to actual defoliation (r=0.30). A simple linear regression of actual to predicted defoliation is shown in Figure 5. The regression line is defined by: A = 7.18262 + 0.432684 (P). The r^2 for the line is 0.089. The student's t-test for the intercept (H_0: a=0) was not significant (t=1.56, p=0.1228) while the t-tests for the slope (H_o: b=0; b=1) was significant (t = 2.51, p = 0.0144; t = -3.295, p = 0.001).

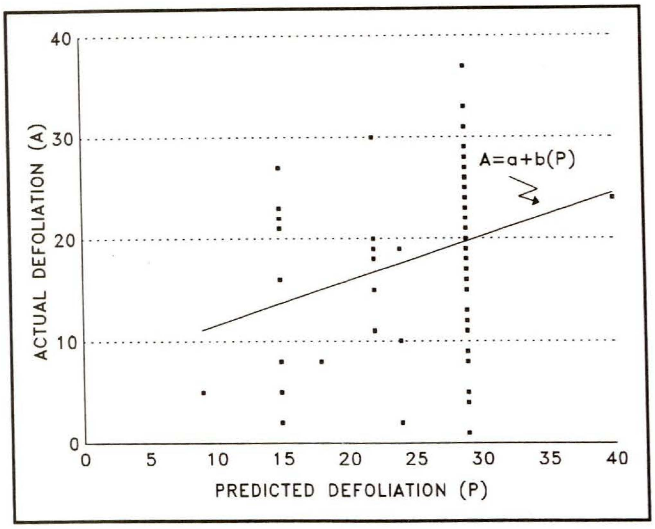


Figure 5.—Regression of 3-year defoliation levels to predicted defoliation levels using Herrick and Gansner model.

DISCUSSION

This paper describes the results of applying a model developed in central Pennsylvania that predicts stand level defoliation to two test data sets: one data set is from the Appalachian Plateau of southwestern Pennsylvania, the other is from the Ridge and Valley of western Maryland. An important limitation of this "case study" approach to validation is the difficulty of obtaining test data that is fully comparable with the model building data set. The results of this validation are affected by differences in initial stand characteristics, defoliation histories, and gypsy moth population levels between stands used to build and test the model. Therefore, this paper demonstrates the capability of the Herrick and Gansner AID model as a predictor of the 3-year average defoliation for these two data sets. Further testing with other data sets may yield more favorable results.

The two data sets used to test the AID model have similarities and differences in stand characteristics with the central Pennsylvania data. Comparing the year of most widespread defoliation for the three areas, the central Pennsylvania data and the Ridge and Valley data had a similar proportion of their plots in the severe defoliation category (45% and 47% respectively); however, 80 percent of the Appalachian Plateau plots had severe defoliation at the peak of defoliation. On average, plots from both the Appalachian Plateau and the Ridge and Valley data had larger mean stand diameters, greater basal area per acre, fewer stems per acre, and lower site quality than plots in the central Pennsylvania data. In the Appalachian Plateau, eight stands had more than 30% defoliation for two or more years, while no stands in the Ridge and Valley had more than one year of severe defoliation. The maximum defoliation category for the AID model is 40 percent. No plots in the Ridge and Valley exceeded 40 percent defoliation; however, 27 percent of the Appalachian Plateau plots had 3-year defoliation averages in excess of this amount. The duration of intense defoliation in the Appalachian Plateau stands partially explains why the AID model underpredicted defoliation in these data. The lack of a sustained defoliation in the Ridge and Valley partially explains why the AID model overpredicted the defoliation in these data.

In both provinces, the standard deviation of the actual defoliation is nearly twice that of the predicted defoliation. The test data represent mixed-oak stands containing a high percentage of oak. Therefore, there was little variation in the parameters that define the AID model, resulting in little variation in the amounts of defoliation predicted. In fact, the AID model predicts that two-thirds of the the Ridge and Valley plots would be in the a single defoliation class (29 percent). In contrast, there was wide variation in the amount of actual defoliation during the study.

The reason for the high number of Ridge and Valley plots being placed in a single defoliation class is evident from Figure 1. Oak trees accounted for more than 80 percent of the basal area in these plots; but, chestnut oak and black oak made up less than 70 percent of the basal area. Also, more than 30 percent of the trees on these plots had good crowns before gypsy moth defoliation. These initial stand conditions yield a predicted amount of defoliation of 29 percent.

Though the AID model did not predict the magnitude of defoliation for the test data plots, if the model can predict that plots are likely to have the greatest amount of defoliation, then the model could still be a useful planning tool. The defoliation level predicted by the model was positively correlated to the actual defoliation levels in both provinces, though the relationship was stronger in the Appalachian Plateau than in the Ridge and Valley. Figures 2 and 4 show that those plots predicted to have high defoliation levels generally did have higher actual defoliation levels than plots predicted to have low defoliation values. This suggests that the major problem with the AID model is problem of scale and not a problem of direction. Therefore, the model may be useful for segregating stands into low priority and high priority areas.

The extensive literature on gypsy moth impacts suggests that forest managers need a tool, such as the AID model, for predicting defoliation levels before gypsy moth populations build to defoliating levels. However, the validation presented in this paper suggests that this model needs further testing and refinement to be used for this purpose. Part of the problem appears to be the wide variation in the defoliation of stands that have similar characteristics. The shortcomings of the AID model may simply reflect a need for additional data in model development. Montgomery (1990) stated that there is too much emphasis on the amount of non-preferred species in model development. If he is correct, we may need to concentrate model building efforts on stands that are 60 to 100 percent preferred species. In order to take this approach, it may be necessary to combine data from as many sources as possible. Currently, five major data sets that were designed to study gypsy moth impacts exist: the Melrose Highlands data (Campbell and Sloan 1977), the Pocono data (Gansner and Herrick 1979), the central Pennsylvania data (Herrick and Gansner 1986), the Appalachian Plateau, and the Ridge and Valley data (Fosbroke et al. 1991). Though there are significant differences in the data collected in these studies, integration of multiple data sets into a single analysis may provide a better accounting of the variation in defoliation between stands than has been possible in past studies.

LITERATURE CITED

Barbosa, P. 1978. Host plant exploitation by the gypsy moth, Lymantria dispar. Ent. Exp. & Appl. 24:28-37.

Barbosa, P., M. Waldvogel, P. Martinat, and L.W. Douglass. 1983. Developmental and reproductive performance of the gypsy moth, Lymantria dispar(L.)(Lepidoptera:Lymantriidae), on selected hosts common to mid-atlantic and southern forests. Environ. Entomol. 12:1858-1862.

Berisford, C. W. and M. E. Montgomery. 1990. Performance of gypsy moth larvae on hosts from the Deep South: survival, development, and host preference. P. 48 *in*: Proc., USDA interagency gypsy moth research review, K. W. Gottschalk, M. J. Twery, and S. I. Smith (eds.). East Windsor, CT. Jan. 22-25. USDA For. Serv. Gen. Tech. Rep. NE-146.

Campbell, R. W. and R. J. Sloan. 1977. Forest stand responses to defoliation by the gypsy moth. For. Sci. Monogr. No. 19. 34p.

Campbell, R. W. and J. P. Standaert. 1974. Forecasting defoliation by the gypsy moth in oak stands. USDA-For. Serv. Res. Note NE-193. 7p.

Crow, G. R. and R. R. Hicks, Jr. 1990. Factors influencing tree mortality in mixed-oak stands following spring insect defoliation. For. Sci. 36:831-841.

Forbush, E. H. and C. H. Fernald. 1896. The gypsy moth. Wright and Potter Publishing. Boston, MA.

Fosbroke, D. E., R. R. Hicks, Jr., and K. W. Gottschalk. 1991. Predicting tree mortality following gypsy moth defoliation. P. 583-585 *in*: Proc., 8th central hardwood forest conference, L. H. McCormick and K. W. Gottschalk (eds.). Pennsylvania State University, University Park, PA. March 3-6.

Fosbroke, D. E. and R. R. Hicks, Jr. 1989. Tree mortality following gypsy moth defoliation. P. 74-80 *in*: Proc., 7th central hardwood forest conference. Carbondale, Il. March 5-7. USDA For. Serv. Gen Tech Rep NC-132.

Gansner, D. A. and O. W. Herrick. 1985. Host preferences of the gypsy moth on a new frontier of infestation. USDA For. Serv. Res. Note NE-330. 3p.

Gansner, D. A. and O. W. Herrick. 1979. Forest stand losses to gypsy moth in the Pocono's. USDA For. Serv. Res. Note. NE-273. 5p.

Gansner, D. A., O. W. Herrick, and M. Ticehurst. 1985. A method for predicting gypsy moth defoliation from egg mass counts. North. J. Appl. For. ?(2):78-79.

Gottschalk, K. W. 1993. Silvicultural guidelines for forest stands threatened by the gypsy moth. USDA For. Serv. Gen. Tech. Rep. NE-171. 49p.

Gottschalk, K. W. 1987. Prevention: the silvicultural alternative. P. 92-104 *in*: Proc., coping with the gypsy moth in the new frontier, S. L. C. Fosbroke and R. R. Hicks, Jr. (eds.). West Virginia University, Morgantown WV. Aug 4-6.

Herrick, O. W. and D. A. Gansner. 1986. Rating forest stands for gypsy moth defoliation. USDA-For. Serv. Res. Paper NE-583. 4p.

Hix, D. M., D. E. Fosbroke, R. R. Hicks, Jr., and K. W. Gottschalk. 1991. Development of regeneration following gypsy moth defoliation of the Appalachian Plateau and Ridge and Valley hardwood stands. P. 347-359 *in*: Proc., 8th central hardwood forest conference, L. H. McCormick and K. W. Gottschalk (eds.). Pennsylvania State Univeristy, University Park, PA. March 4-6.

Hodkinson, I.D. and M.K. Hughes. 1982. Insect Herbivory:Outline Studies in Ecology. Chapman and Hall, Ltd. NY, NY. 77p.

Houston, D. R. and H. T. Valentine. 1985. Classifying Forest Susceptibility to gypsy moth defoliation. USDA Agric. Hdbk No. 542. 19p.

Kegg, J. D. 1973. Oak mortality caused by repeated gypsy moth defoliation in New Jersey. J. Econ. Ent. 66:639-641.

Kleiner, K. W., M. E. Montgomery, and J. C. Schultz. 1989. Variation in leaf quality of two oak species: implications for stand susceptibility to gypsy moth defoliation. Can. J. For. Res. 19:1445-1450.

Mason, G. N., D. A. Gansner, and K. W. Gottschalk. 1986. Helping forest managers cope with the gypsy moth. P. 216-133 *in*: Proc., integrated pest management symposium for northern forests. University of Wisconsin, Madison, WI. March 24-27.

Miller, J. C. and P. E. Hanson. 1989. Laboratory studies on development of gypsy moth, *Lymantria dispar* (L.) (LEPIDOPTERA:LYMANTRIIDAE), larvae on foliage of gymnosperms. Can. Ent. 121(6):425-429.

Montgomey, M. E. 1990. Variation in the suitability of tree species for the gypsy moth. P. 1-13 *in*: Proc., USDA interagency gypsy moth research review, K. W. Gottschalk, M. J. Twery, and S. I. Smith (eds.). East Windsor, CT. Jan. 22-25. USDA For. Serv. Gen. Tech. Rep. NE-146.

Mosher, F. H. 1915. Food plants of the gipsy moth in america. USDA Bul. No. 250. 39p.

Stephens, G. R. 1988. Mortality, dieback, and growth of defoliated hemlock and white pine. North. J. Appl. For. 5(2):93-96.

Twery, M. J. 1990. Effects of defoliation by the gypsy moth. P. 27-39 *in*: Proc. USDA interagency gypsy moth research review, K. W. Gottschalk, M. J. Twery, and S. I. Smith (eds.). East Windsor, CT. Jan. 22-25. USDA For. Serv. Gen. Tech. Rep. NE-146.

Valentine, H. T. and D. R. Houston. 1984. Identifying mixed-oak stand susceptibility to gypsy moth defoliation: an update. For. Sci. 30(1):270-271.

Valentine, H. T. and D. R. Houston. 1979. A discriminent function for identifying mixed-oak stand susceptibility to gypsy moth defoliation. For. Sci. 25:468-474.

Witter, J. A., M. E. Montgomery, C. A. Chilcote, and J. L. Stoyenoff. 1990. The effects of tree species and site conditions on gypsy moth survival and growth in Michigan. P. 47 *in:* Proc. USDA interagency gypsy moth research review, K. W. Gottschalk, M. J. Twery, and S. I. Smith (eds.). East Windsor, CT. Jan. 22-25 USDA For. Serv. Gen. Tech. Rep. NE-146.

Mapping the Defoliation Potential of Gypsy Moth

David A. Gansner, Stanford L. Arner, Rachel Riemann Hershey, and Susan L. King[1]

Abstract: A model that uses forest stand characteristics to estimate the likelihood of gypsy moth (Lymantria dispar) defoliation has been developed. It was applied to recent forest inventory plot data to produce susceptibility ratings and a map showing defoliation potential for counties in Pennsylvania and six adjacent states on new frontiers of infestation.

Levels of defoliation vary greatly within areas infested by the gypsy moth. So, practical methods for identifying highly susceptible locations (that is, those most likely to suffer heavy defoliation during an infestation) would greatly aid forest resource and pest managers. A model that uses forest stand characteristics to estimate the likelihood of gypsy moth defoliation has been developed. Its application to recent forest inventory plot data has resulted in susceptibility ratings and a map showing defoliation potential for counties in Pennsylvania and six surrounding states on new frontiers of infestation.

DEFOLIATION MODEL

The combined relationship that 38 stand condition variables had with average defoliation during a gypsy moth outbreak was analyzed for 575 forest plots in central Pennsylvania. A technique called Automatic Interaction Detection was used to search characteristics of trees and plots for the best predictors of susceptibility (Sonquist et al. 1973). This analysis made it possible to assign potential rates of defoliation to forest stands (Herrick and Gansner 1986). Other methods for estimating susceptibility have been developed (for example, Valentine and Houston 1979). But to our knowledge, the Herrick/Gansner model is the only one available that links defoliation severity to key forest stand characteristics as predictor variables on new frontiers of infestation (Figure 1).

Only four of the many stand characteristics analyzed as predictors of defoliation were retained in the model: percentage of basal area in oaks, percentage of basal area in chestnut and black oaks, percentage of basal area in trees with good crowns, and average diameter of the stand. From 1980-82, defoliation for all sample plots in the central Pennsylvania study averaged 26 percent and ranged from <1 to 70 percent. The model identified the highest average defoliation in plots that had at least 80 percent basal area in oakspecies, at least 70 percent basal area in chestnut and black oaks, and at least 60 percent basal area in trees with good crowns. Plots with the lowest average defoliation had less than 20 percent basal area in oaks.

---

[1] The authors are, respectively, Research Forester, Resource Analyst, Forester/Geographer, and Operations Research Analyst with the Forest Inventory and Analysis Project, USDA Forest Service, Northeastern Forest Experiment Station, 5 Radnor Corporate Center, 100 Matsonford Rd., Suite 200, Radnor, PA 19087-4585.

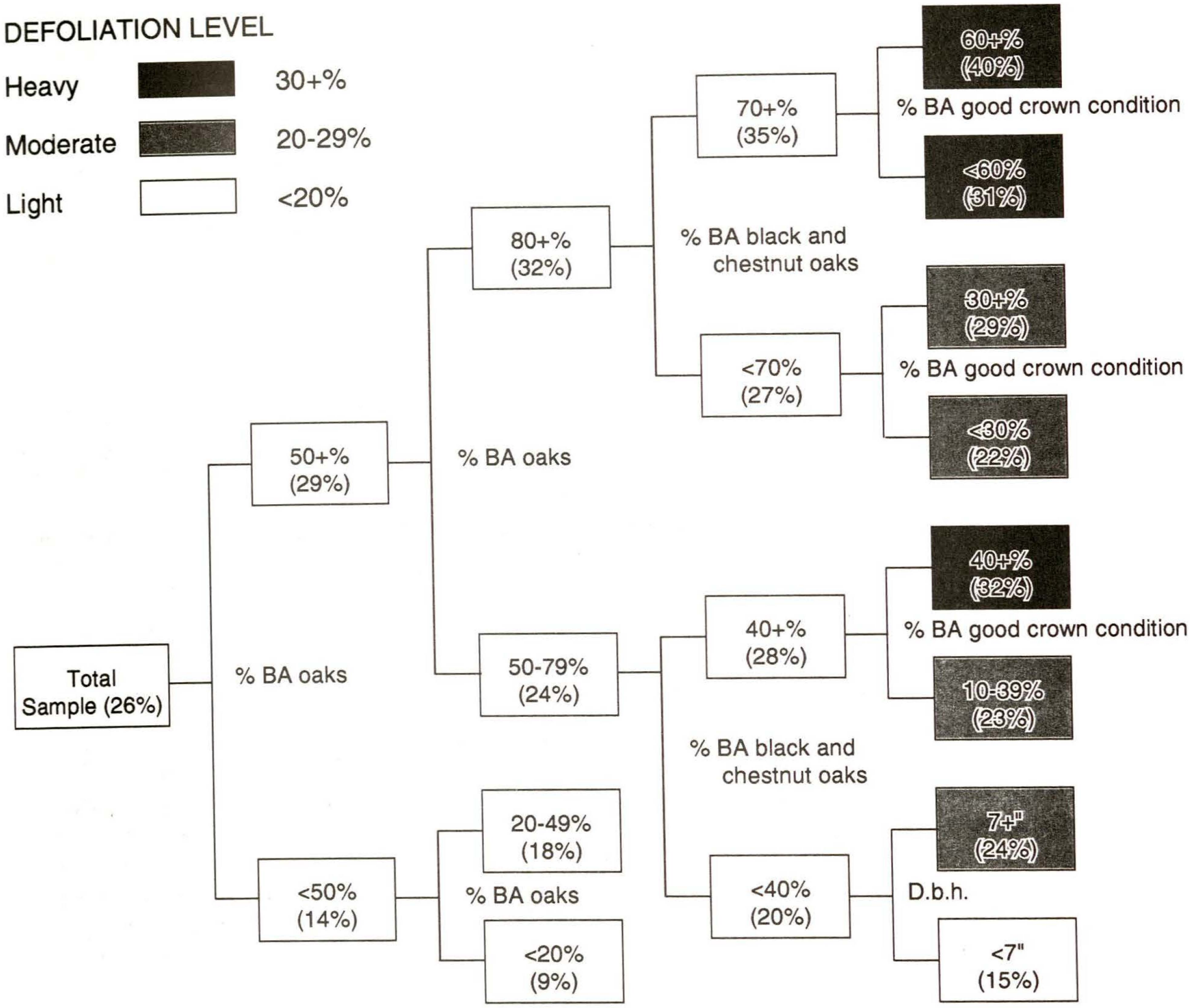

DEFOLIATION LEVEL
Heavy 30+%
Moderate 20-29%
Light <20%
Total Sample (26%)
% BA oaks
50+% (29%)
<50% (14%)
% BA oaks
80+% (32%)
50-79% (24%)
% BA oaks
20-49% (18%)
<20% (9%)
% BA black and chestnut oaks
70+% (35%)
<70% (27%)
% BA black and chestnut oaks
40+% (28%)
<40% (20%)
% BA good crown condition
60+% (40%)
<60% (31%)
% BA good crown condition
30+% (29%)
<30% (22%)
% BA good crown condition
40+% (32%)
10-39% (23%)
D.b.h.
7+" (24%)
<7" (15%)

Figure 1.—Guide for estimating gypsy moth defoliation potential. Any hardwood stand can be assigned to defoliation group on the basis of characteristics of the stand. The 3-year average defoliation percentage is shown in parentheses for each group.

FOREST INVENTORY DATA BASE

The USDA Forest Service updates statewide timber resource information approximately every 10 years. The last inventory of Pennsylvania was completed for 1989. Latest reinventories for the six other states included in this analysis were: Delaware-1986, Kentucky-1988, Maryland-1986, Ohio-1990, Virginia-1986, and West Virginia-1989. Thousands of ground plots were measured in these seven states. Measurements from those plots provided the data base for mapping defoliation potential.

PROCEDURE

The defoliation potential model was used to calculate susceptibility ratings for all of the forest inventory ground plots in Pennsylvania and the six surrounding states. By design, each inventory plot represents a given proportional share of the forest area in a county. So, appropriate weights could be applied to plot data to derive average susceptibility ratings for each county. Exceptions are counties designated nonforest (such as Philadelphia county in Pennsylvania) where no ground plots have been sampled.

Only three of the four variables included in the defoliation potential model could be used in the analysis. Crown condition was not measured by forest inventory crews and no appropriate surrogates for the crown condition variable are available. This is not a serious problem because crown condition does not account for a large amount of the variation in defoliation.

The process of assigning susceptibility ratings to counties began with Pennsylvania. Values were calculated for each of Pennsylvania's forested counties using data from the 1978 inventory. Ratings ranged from a high of 26.8 for York to a low of 9 for Erie (Figure 2). Rating class boundaries of <12, to 17.9, and 18+ were used tosort Pennsylvania's counties into three groups representing low, medium, and high levels of defoliation potential (Figure 3). This grouping correlates well with the history of annual gypsy moth defoliation recorded on rough sketch maps since 1978. Satisfied with these results for Pennsylvania, we applied the methodology to the most recent forest inventory plot data available to compute susceptibility ratings for counties in all seven states (Figures 4-9).

RESULTS AND IMPLICATIONS

The final products of this effort are susceptibility ratings and maps showing current defoliation potential, by county, in a 7-state area where gypsy moth is an immediate concern (Figure 10). There are no major surprises here. Counties with the highest susceptibility ratings are those where oaks, especially chestnut and black, are major components of the forest. Low ratings reflect the prevalence of species such as yellow-poplar, ash, red maple, and black cherry that rank lower on the list of preferred hosts (Gansner and Herrick 1985).

Of course, counties with low susceptibility ratings can contain areas with high defoliation potential and vice versa. Also, average ratings tell us nothing about the amount or location of susceptible forest within a county. For example, Pike and Lebanon counties in Pennsylvania both have high ratings but Pike has five times more forest land. Ratings for counties with very little forest are based on data from very few ground plots and may be subject to high sampling errors. Individual plot locations are now being digitized to gain a better breakdown for critical spots.

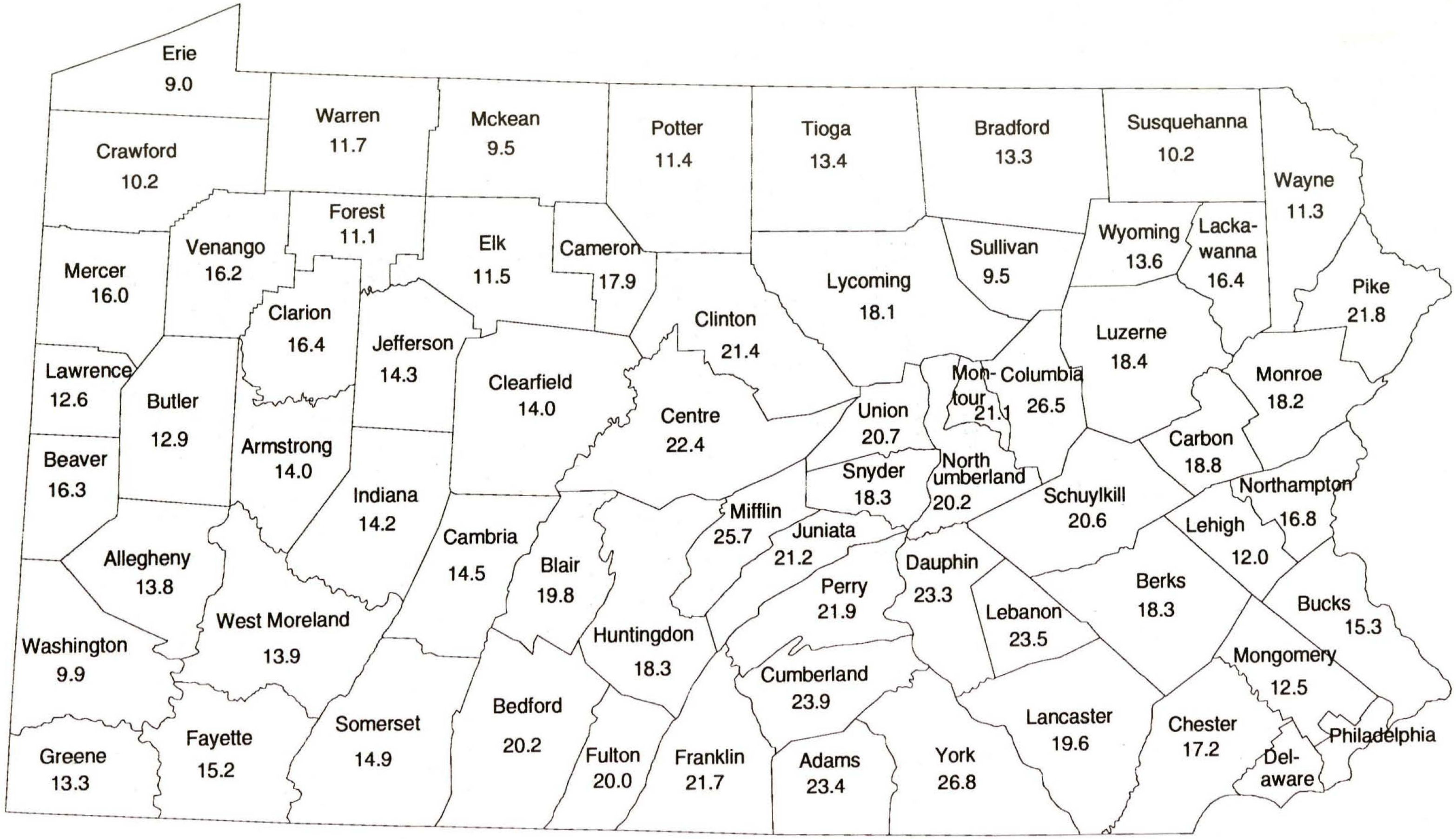

Erie 9.0
Crawford 10.2
Warren 11.7
Mckean 9.5
Potter 11.4
Tioga 13.4
Bradford 13.3
Susquehanna 10.2
Wayne 11.3
Mercer 16.0
Venango 16.2
Forest 11.1
Elk 11.5
Cameron 17.9
Clinton 21.4
Lycoming 18.1
Sullivan 9.5
Wyoming 13.6
Lacka-wanna 16.4
Pike 21.8
Lawrence 12.6
Butler 12.9
Clarion 16.4
Jefferson 14.3
Clearfield 14.0
Centre 22.4
Union 20.7
Mon-tour 21.1
Columbia 26.5
Luzerne 18.4
Monroe 18.2
Beaver 16.3
Armstrong 14.0
Indiana 14.2
Snyder 18.3
North umberland 20.2
Carbon 18.8
Schuylkill 20.6
Northampton 16.8
Allegheny 13.8
Cambria 14.5
Blair 19.8
Mifflin 25.7
Juniata 21.2
Dauphin 23.3
Lehigh 12.0
Berks 18.3
Washington 9.9
West Moreland 13.9
Huntingdon 18.3
Perry 21.9
Lebanon 23.5
Bucks 15.3
Cumberland 23.9
Mongomery 12.5
Greene 13.3
Fayette 15.2
Somerset 14.9
Bedford 20.2
Fulton 20.0
Franklin 21.7
Adams 23.4
York 26.8
Lancaster 19.6
Chester 17.2
Del-aware
Philadelphia

Figure 2.—Gypsy moth susceptibility ratings for Pennsylvania, by county, 1978.

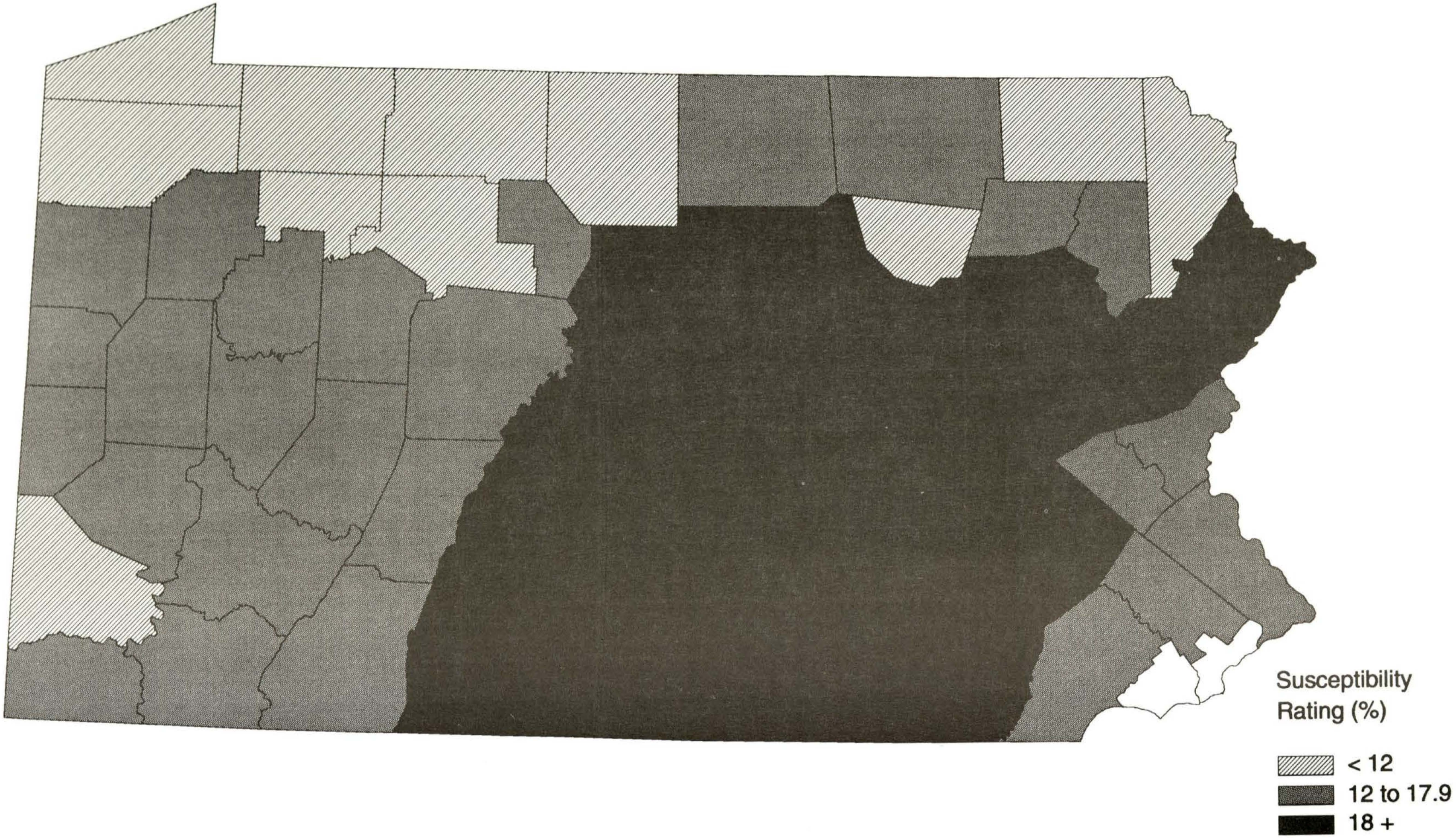

Susceptibility
Rating (%)
▨ < 12
▩ 12 to 17.9
■ 18 +

Figure 3.—Gypsy moth defoliation for Pennsylvania, by county, 1978.

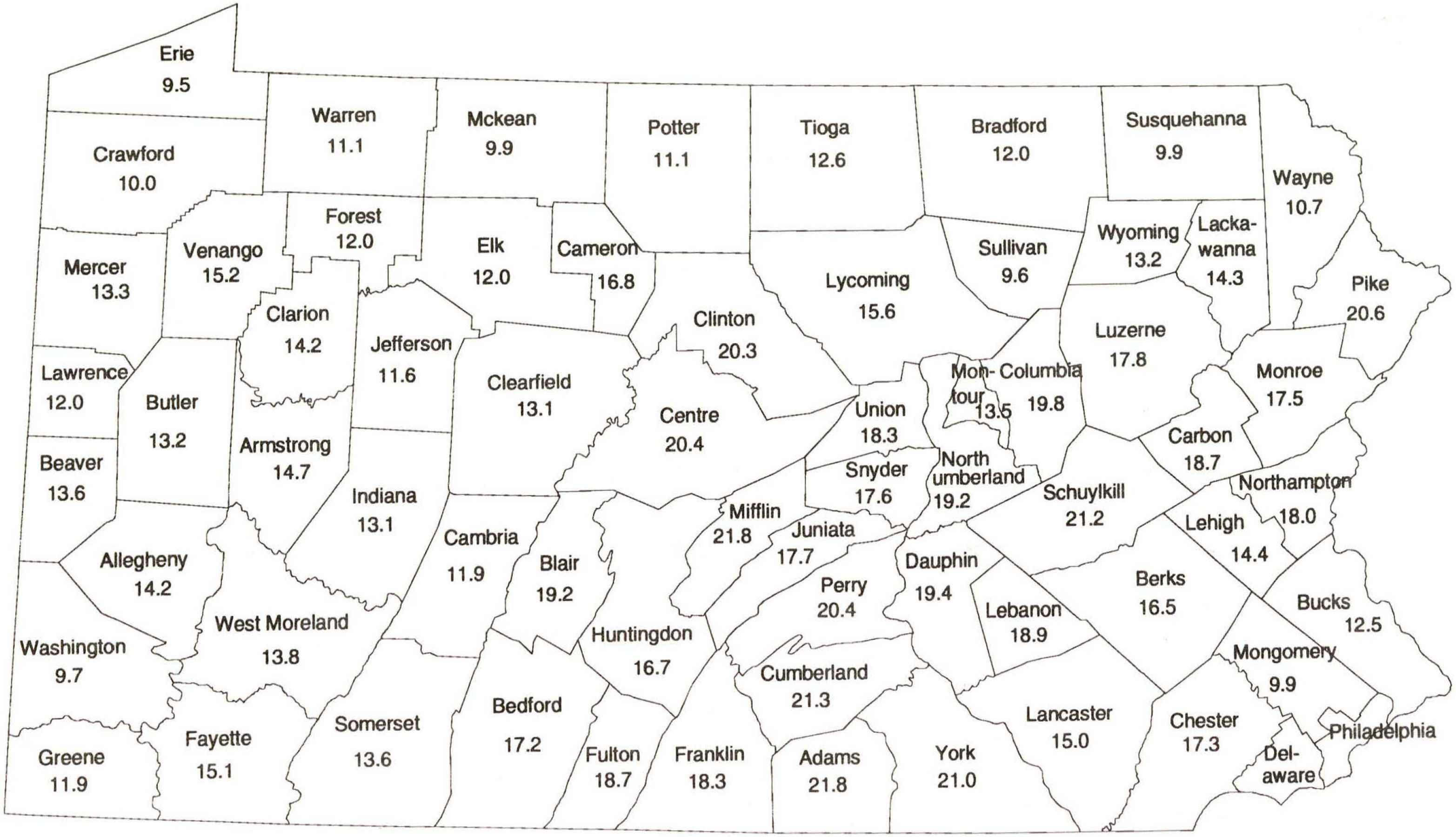

Erie 9.5
Crawford 10.0
Warren 11.1
Mckean 9.9
Potter 11.1
Tioga 12.6
Bradford 12.0
Susquehanna 9.9
Wayne 10.7
Mercer 13.3
Venango 15.2
Forest 12.0
Elk 12.0
Cameron 16.8
Clinton 20.3
Lycoming 15.6
Sullivan 9.6
Wyoming 13.2
Lacka-wanna 14.3
Pike 20.6
Lawrence 12.0
Butler 13.2
Clarion 14.2
Jefferson 11.6
Clearfield 13.1
Centre 20.4
Union 18.3
Mon-tour 13.5
Columbia 19.8
Luzerne 17.8
Monroe 17.5
Beaver 13.6
Armstrong 14.7
Indiana 13.1
Snyder 17.6
North umberland 19.2
Carbon 18.7
Schuylkill 21.2
Northampton 18.0
Allegheny 14.2
Cambria 11.9
Blair 19.2
Mifflin 21.8
Juniata 17.7
Dauphin 19.4
Lehigh 14.4
Perry 20.4
Berks 16.5
Bucks 12.5
Washington 9.7
West Moreland 13.8
Huntingdon 16.7
Lebanon 18.9
Cumberland 21.3
Mongomery 9.9
Greene 11.9
Fayette 15.1
Somerset 13.6
Bedford 17.2
Fulton 18.7
Franklin 18.3
Adams 21.8
York 21.0
Lancaster 15.0
Chester 17.3
Del-aware
Philadelphia

Figure 4.—Susceptibility ratings for Pennsylvania, by county, 1989.

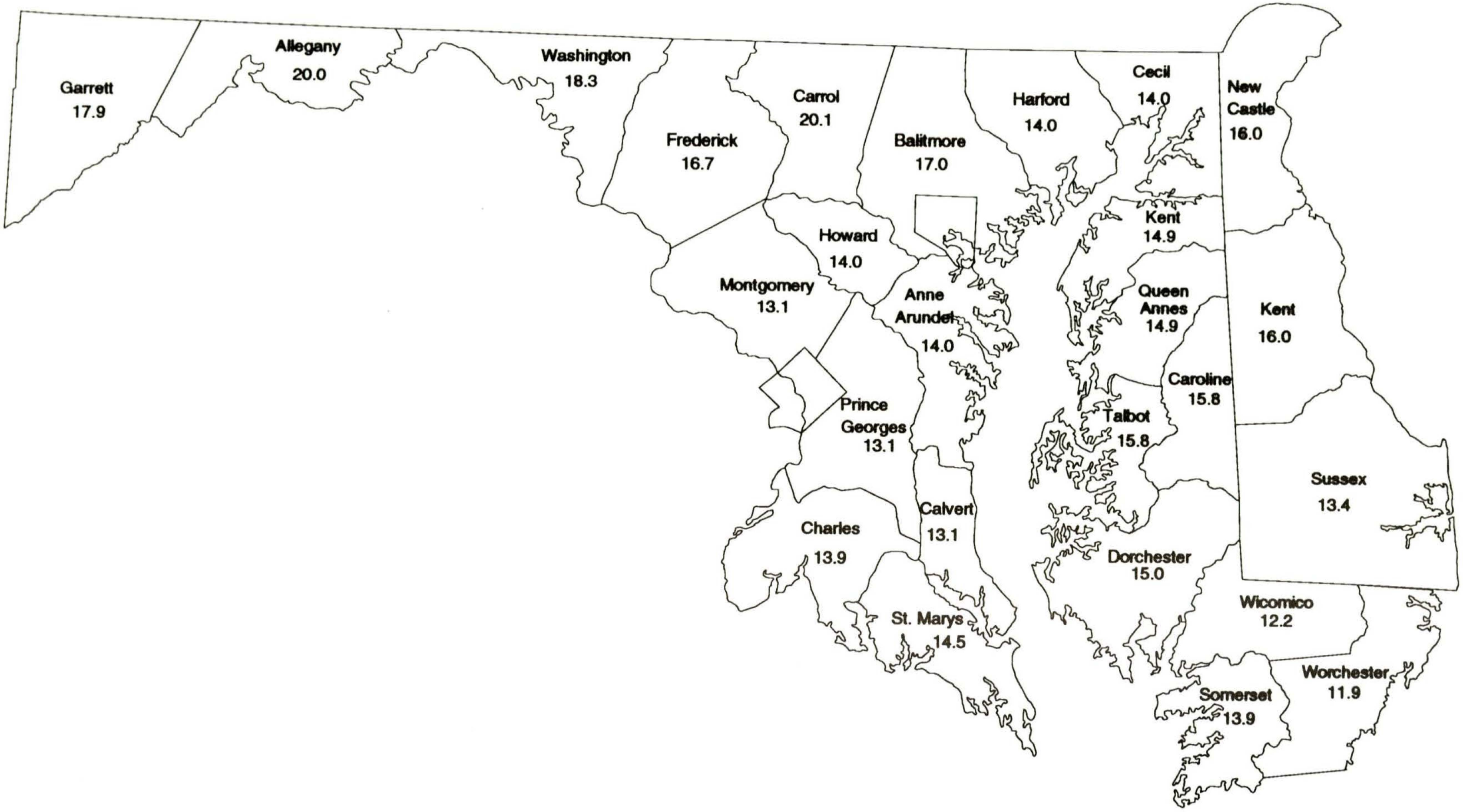

Garrett
17.9
Allegany
20.0
Washington
18.3
Frederick
16.7
Carrol
20.1
Balitmore
17.0
Harford
14.0
Cecil
14.0
New
Castle
16.0
Kent
14.9
Howard
14.0
Montgomery
13.1
Anne
Arundel
14.0
Queen
Annes
14.9
Kent
16.0
Caroline
15.8
Talbot
15.8
Prince
Georges
13.1
Sussex
13.4
Calvert
13.1
Charles
13.9
Dorchester
15.0
St. Marys
14.5
Wicomico
12.2
Worchester
11.9
Somerset
13.9

Figure 5.—Susceptibility ratings for Maryland and Delaware, by county, 1986.

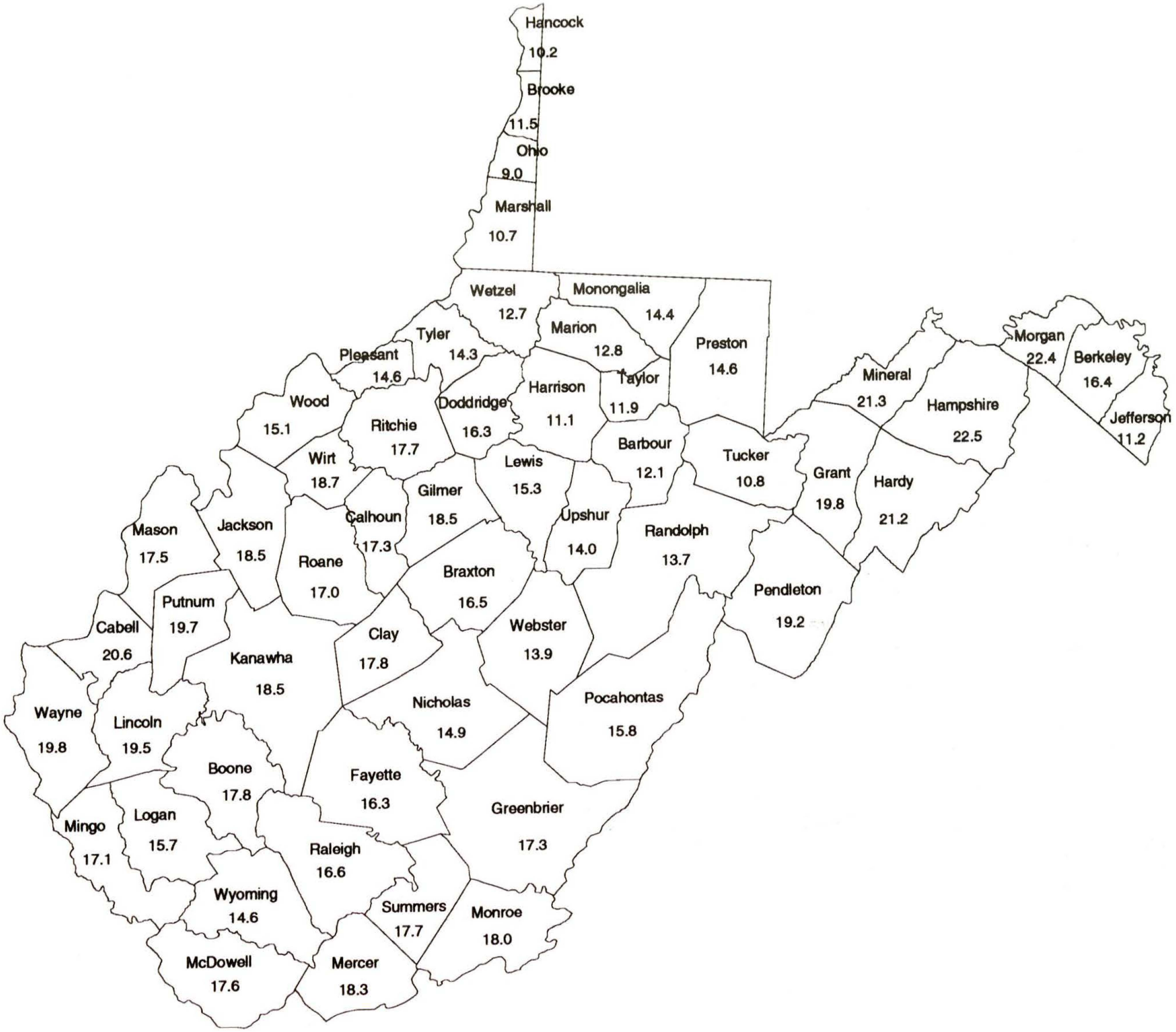

Hancock
10.2
Brooke
11.5
Ohio
9.0
Marshall
10.7
Wetzel
12.7
Monongalia
14.4
Marion
12.8
Preston
14.6
Tyler
14.3
Pleasant
14.6
Taylor
11.9
Harrison
11.1
Doddridge
16.3
Wood
15.1
Ritchie
17.7
Wirt
18.7
Barbour
12.1
Lewis
15.3
Tucker
10.8
Gilmer
18.5
Calhoun
17.3
Upshur
14.0
Mason
17.5
Jackson
18.5
Roane
17.0
Randolph
13.7
Braxton
16.5
Putnum
19.7
Cabell
20.6
Clay
17.8
Webster
13.9
Kanawha
18.5
Pendleton
19.2
Wayne
19.8
Lincoln
19.5
Nicholas
14.9
Pocahontas
15.8
Boone
17.8
Fayette
16.3
Greenbrier
17.3
Mingo
17.1
Logan
15.7
Raleigh
16.6
Wyoming
14.6
Summers
17.7
Monroe
18.0
McDowell
17.6
Mercer
18.3
Mineral
21.3
Morgan
22.4
Berkeley
16.4
Hampshire
22.5
Jefferson
11.2
Grant
19.8
Hardy
21.2

Figure 6.—Susceptibility ratings for West Virginia, by county, 1989.

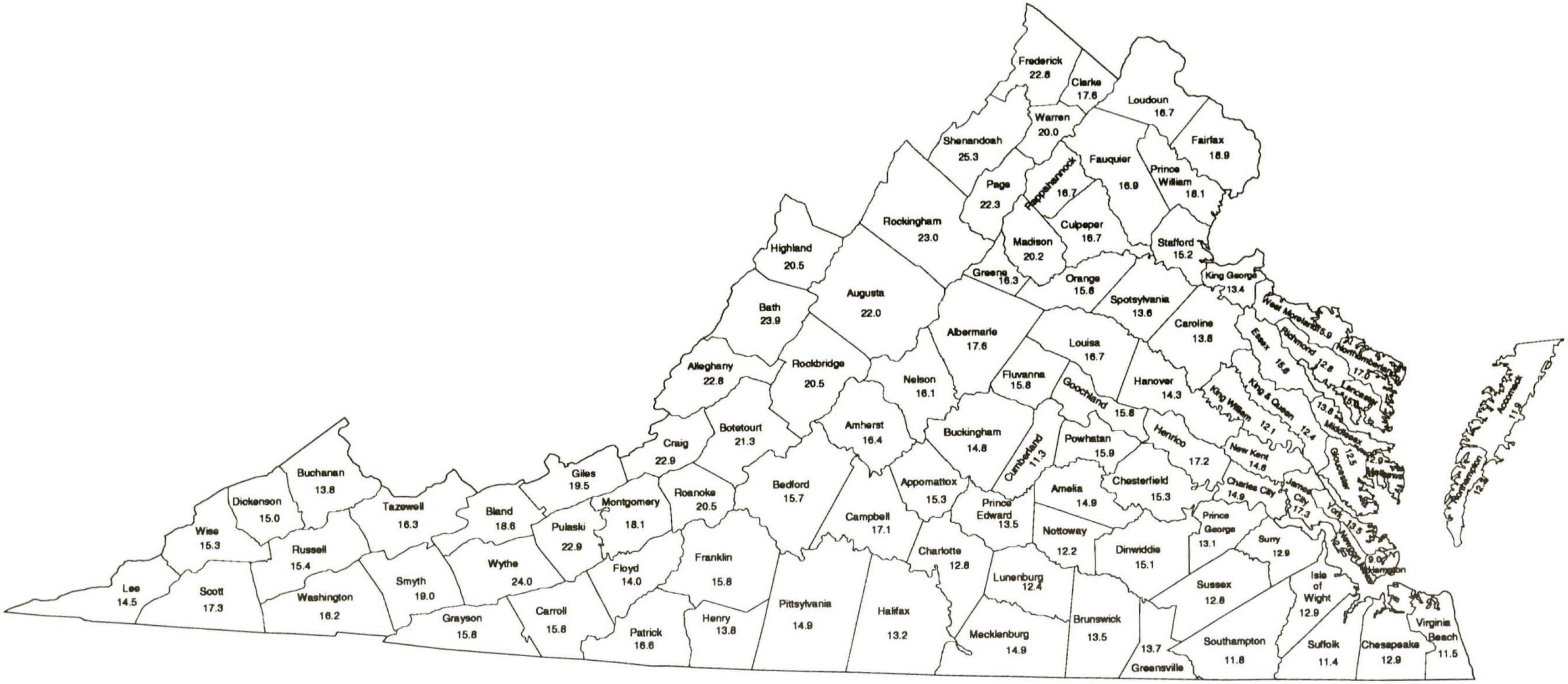

Frederick
22.8
Clarke
17.6
Loudoun
16.7
Warren
20.0
Fairfax
18.9
Shenandoah
25.3
Fauquier
16.9
Prince
William
18.1
Page
22.3
Rappahannock
16.7
Culpeper
16.7
Rockingham
23.0
Madison
20.2
Stafford
15.2
Highland
20.5
Greene
18.3
Orange
15.8
King George
13.4
Augusta
22.0
Spotsylvania
13.6
Bath
23.9
Caroline
13.8
West Moreland
15.9
Albermarle
17.6
Louisa
16.7
Essex
15.6
Richmond
12.8
Northumberland
17.0
Alleghany
22.8
Rockbridge
20.5
Nelson
16.1
Fluvanna
15.8
Hanover
14.3
Lancaster
15.8
Goochland
15.6
King William
12.1
King & Queen
12.4
Middlesex
13.8
Accomack
11.9
Amherst
16.4
Buckingham
14.8
Cumberland
11.3
Powhatan
15.9
Henrico
17.2
New Kent
14.6
Gloucester
12.5
Mathews
12.9
Northampton
12.3
Botetourt
21.3
Craig
22.9
Buchanan
13.8
Giles
19.5
Bedford
15.7
Appomattox
15.3
Amelia
14.9
Chesterfield
15.3
Charles City
14.9
James City
17.3
York
13.5
Dickenson
15.0
Tazewell
16.3
Bland
18.6
Montgomery
18.1
Roanoke
20.5
Campbell
17.1
Prince
Edward
13.5
Prince
George
13.1
Newport News
9.0
Hampton
Wise
15.3
Pulaski
22.9
Nottoway
12.2
Surry
12.9
Russell
15.4
Franklin
15.8
Charlotte
12.8
Dinwiddie
15.1
Isle
of
Wight
12.9
Lee
14.5
Scott
17.3
Wythe
24.0
Floyd
14.0
Lunenburg
12.4
Sussex
12.8
Washington
16.2
Smyth
19.0
Carroll
15.8
Pittsylvania
14.9
Halifax
13.2
Virginia
Beach
11.5
Grayson
15.8
Patrick
16.6
Henry
13.8
Mecklenburg
14.9
Brunswick
13.5
13.7
Greensville
Southampton
11.8
Suffolk
11.4
Chesapeake
12.9

Figure 7.—Susceptibility ratings for Virginia, by county, 1986.

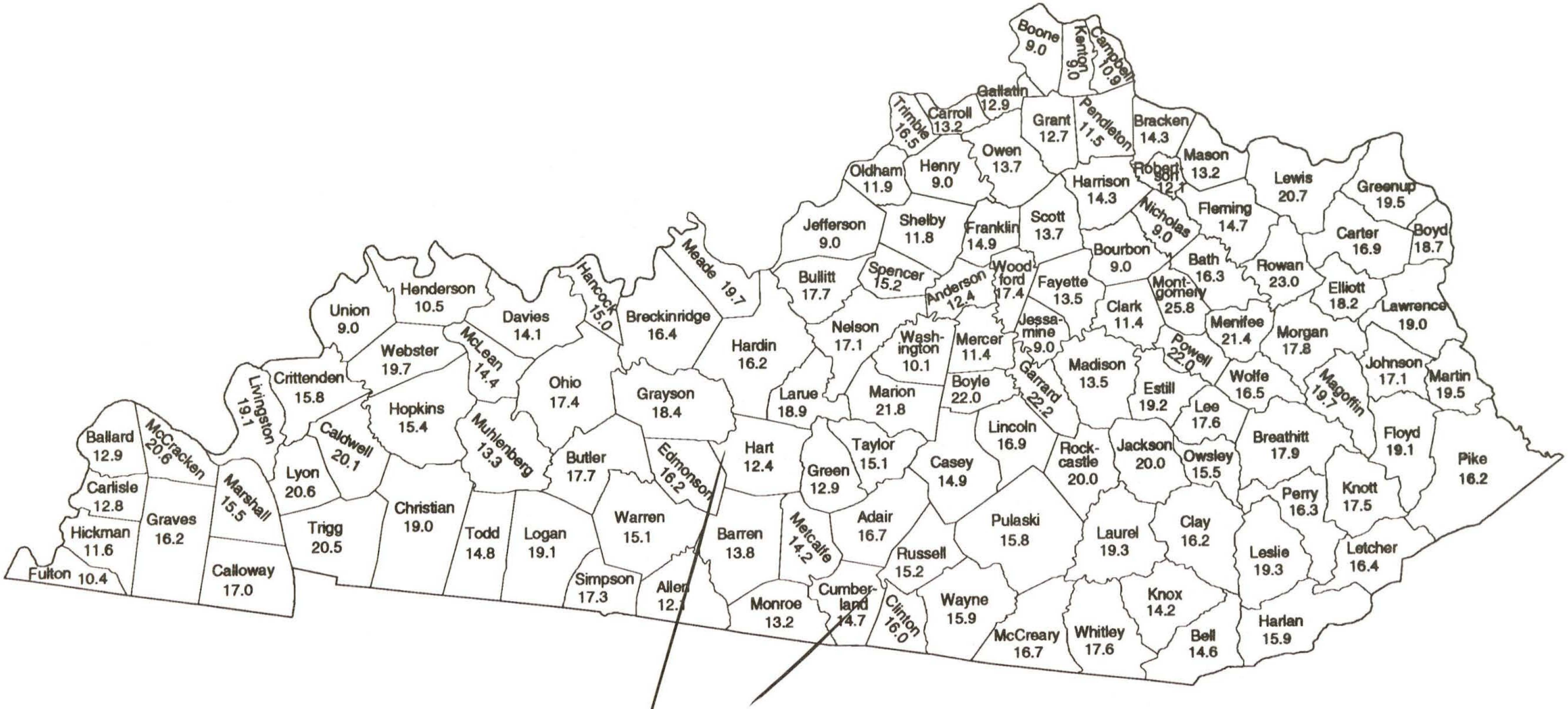

Boone 9.0
Kenton 9.0
Campbell 10.9
Gallatin 12.9
Trimble 16.5
Carroll 13.2
Grant 12.7
Pendleton 11.5
Bracken 14.3
Owen 13.7
Mason 13.2
Robertson 12.1
Oldham 11.9
Henry 9.0
Harrison 14.3
Lewis 20.7
Greenup 19.5
Nicholas 9.0
Fleming 14.7
Jefferson 9.0
Shelby 11.8
Franklin 14.9
Scott 13.7
Carter 16.9
Boyd 18.7
Meade 19.7
Bourbon 9.0
Bath 16.3
Rowan 23.0
Spencer 15.2
Woodford 17.4
Fayette 13.5
Bullitt 17.7
Anderson 12.4
Elliott 18.2
Henderson 10.5
Hancock 15.0
Montgomery 25.8
Clark 11.4
Lawrence 19.0
Union 9.0
Davies 14.1
Breckinridge 16.4
Menifee 21.4
Morgan 17.8
Nelson 17.1
Jessamine 9.0
Hardin 16.2
Washington 10.1
Mercer 11.4
Webster 19.7
McLean 14.4
Powell 22.0
Madison 13.5
Johnson 17.1
Martin 19.5
Crittenden 15.8
Livingston 19.1
Ohio 17.4
Grayson 18.4
Larue 18.9
Marion 21.8
Boyle 22.0
Garrard 22.2
Estill 19.2
Wolfe 16.5
Magoffin 19.7
Lee 17.6
Hopkins 15.4
Ballard 12.9
McCracken 20.6
Caldwell 20.1
Muhlenberg 13.3
Lincoln 16.9
Breathitt 17.9
Floyd 19.1
Hart 12.4
Taylor 15.1
Jackson 20.0
Carlisle 12.8
Lyon 20.6
Butler 17.7
Edmonson 16.2
Casey 14.9
Rockcastle 20.0
Owsley 15.5
Pike 16.2
Green 12.9
Marshall 15.5
Christian 19.0
Perry 16.3
Knott 17.5
Graves 16.2
Hickman 11.6
Warren 15.1
Adair 16.7
Pulaski 15.8
Clay 16.2
Trigg 20.5
Todd 14.8
Logan 19.1
Barren 13.8
Metcalfe 14.2
Laurel 19.3
Leslie 19.3
Letcher 16.4
Russell 15.2
Fulton 10.4
Calloway 17.0
Simpson 17.3
Allen 12.1
Knox 14.2
Monroe 13.2
Cumberland 14.7
Clinton 16.0
Wayne 15.9
Harlan 15.9
McCreary 16.7
Whitley 17.6
Bell 14.6

Figure 8.—Susceptibility ratings for Kentucky, by county, 1988.

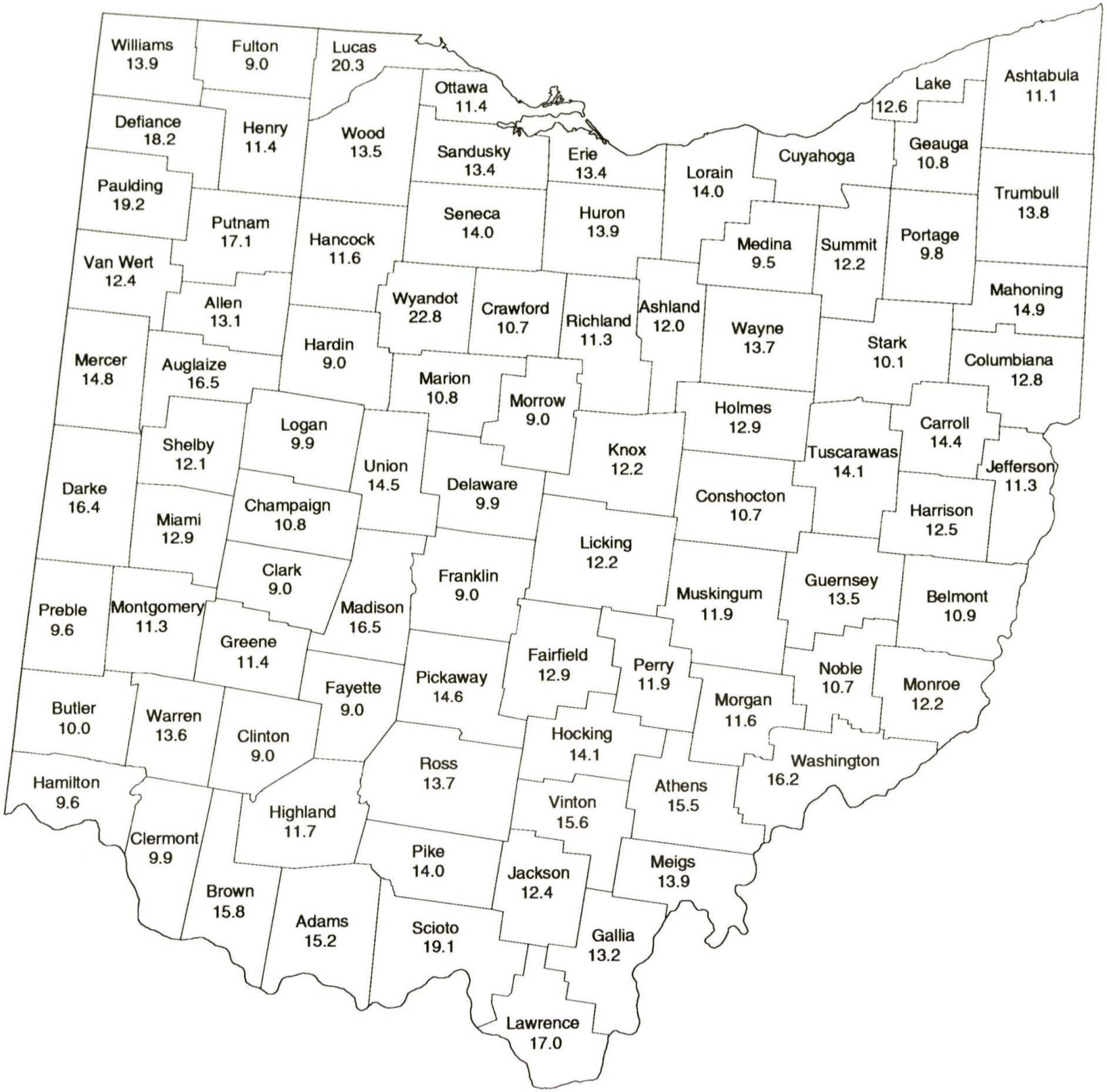

Williams 13.9
Fulton 9.0
Lucas 20.3
Ottawa 11.4
Lake 12.6
Ashtabula 11.1
Defiance 18.2
Henry 11.4
Wood 13.5
Sandusky 13.4
Erie 13.4
Lorain 14.0
Cuyahoga
Geauga 10.8
Trumbull 13.8
Paulding 19.2
Putnam 17.1
Hancock 11.6
Seneca 14.0
Huron 13.9
Medina 9.5
Summit 12.2
Portage 9.8
Van Wert 12.4
Allen 13.1
Wyandot 22.8
Crawford 10.7
Richland 11.3
Ashland 12.0
Wayne 13.7
Stark 10.1
Mahoning 14.9
Mercer 14.8
Auglaize 16.5
Hardin 9.0
Marion 10.8
Morrow 9.0
Holmes 12.9
Carroll 14.4
Columbiana 12.8
Shelby 12.1
Logan 9.9
Union 14.5
Delaware 9.9
Knox 12.2
Tuscarawas 14.1
Jefferson 11.3
Darke 16.4
Miami 12.9
Champaign 10.8
Licking 12.2
Conshocton 10.7
Harrison 12.5
Clark 9.0
Madison 16.5
Franklin 9.0
Muskingum 11.9
Guernsey 13.5
Belmont 10.9
Preble 9.6
Montgomery 11.3
Greene 11.4
Fayette 9.0
Pickaway 14.6
Fairfield 12.9
Perry 11.9
Morgan 11.6
Noble 10.7
Monroe 12.2
Butler 10.0
Warren 13.6
Clinton 9.0
Ross 13.7
Hocking 14.1
Washington 16.2
Hamilton 9.6
Highland 11.7
Vinton 15.6
Athens 15.5
Clermont 9.9
Pike 14.0
Jackson 12.4
Meigs 13.9
Brown 15.8
Adams 15.2
Scioto 19.1
Gallia 13.2
Lawrence 17.0

Figure 9.—Susceptibility ratings for Ohio, by county, 1990.

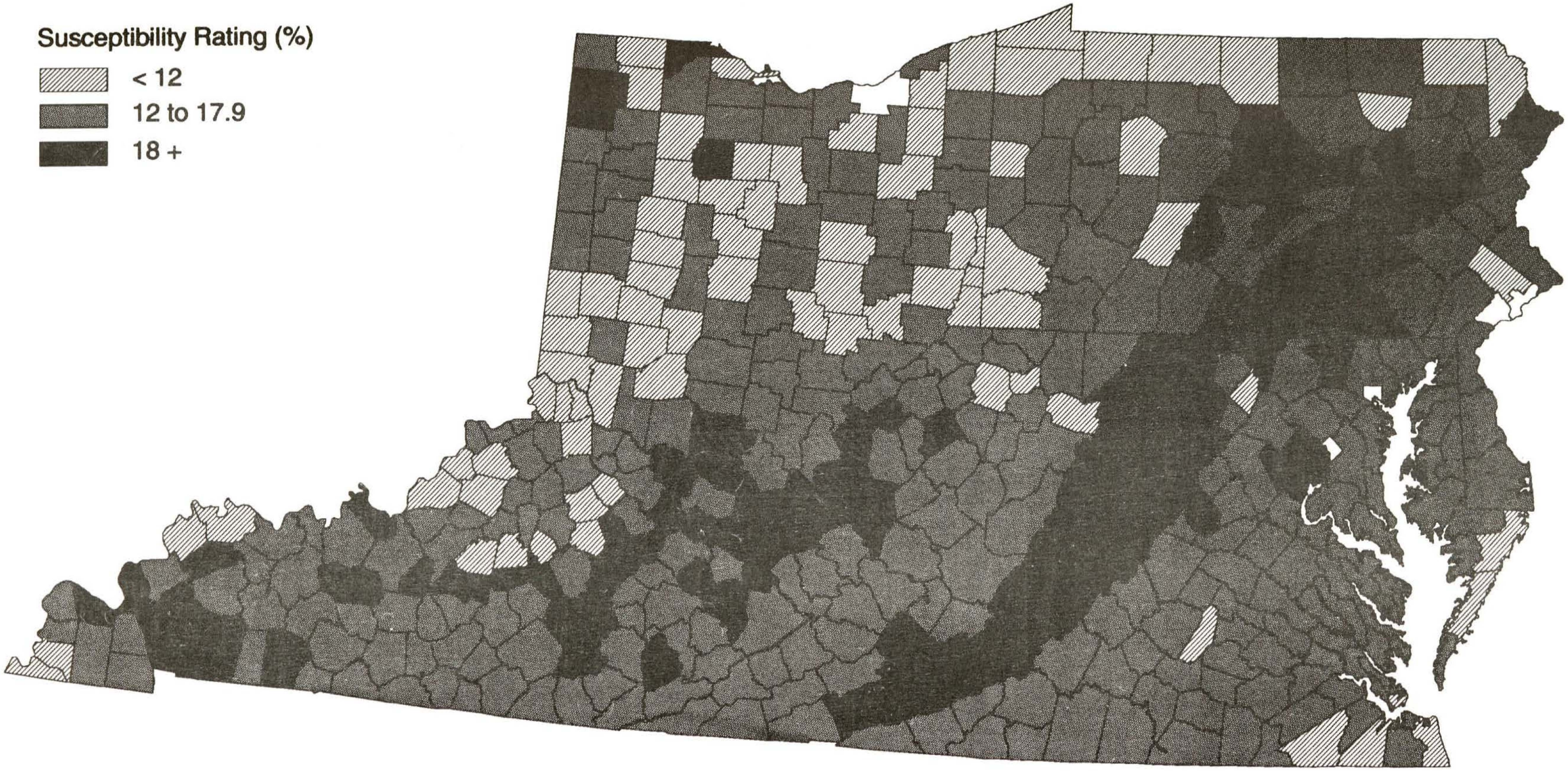

Susceptibility Rating (%)
▨ < 12
▨ 12 to 17.9
■ 18 +

Figure 10.—Gypsy moth defoliation potential in seven threatened states, by county.

A comparison of the Pennsylvania ratings for 1978 (Figure 2) with those for 1989 (Figure 4) indicates a shift in susceptibility for some Pennsylvania counties. For example, Bedford county had a susceptibility rating of 20.2 in 1978. But heavy defoliation and drought during the 1980's led to high mortality, salvage cutting, and growth loss in the oaks. At the same time, less preferred species such as hemlock, yellow-poplar, white ash, black gum, birch, cherry, and red maple flourished. By 1989, Bedford county's susceptibility rating dropped to 17.2. Future research will take a closer look at changes in susceptibility for counties and individual plots.

Opportunities for extending the analysis to other states such as North Carolina, Tennessee, and Indiana also will be explored. The defoliation potential model should yield accurate results for areas with stand characteristics similar to those of the study area where it was developed. But, who can say whether a post oak in the Ozarks of Missouri or sweetgum on the Coastal Plain of South Carolina will hold the same attraction for gypsy moth as a chestnut oak on a ridge in central Pennsylvania. For now, we hope the susceptibility ratings and map of defoliation potential will give resource and pest managers in at least seven threatened states a better understanding of what to expect from the gypsy moth and thus a basis for improved decisions for coping with the pest.

LITERATURE CITED

Gansner, D.A., and O.W. Herrick 1985. Host preferences of gypsy moth on a new frontier of infestation.Research Note NE-330. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 3 p.

Herrick, O.W., and D.A. Gansner 1986. Rating forest stands for gypsy moth defoliation. Research Paper NE-583. Radnor PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 4 p.

Sonquist, J.A., E.D. Baker, and J.M. Morgan 1973. Searching for structure. AnnArbor, MI: University of Michigan, Institute for Social Research, Survey Research Center. 236 p.

Valentine H.T., and D.R. Houston 1979. A discriminant function for. For Sci. 25(3):468-474. identifying mixed-oak stand susceptibility to gypsy moth defoliation

Artificial Regeneration of Northern Red Oak in the Lake States With a Light Shelterwood: A Departure From Tradition

Ronald M. Teclaw and J.G. Isebrands[1]

Abstract: Artificial regeneration of northern red oak is difficult to achieve in the Lake States. A replicated study was established in northern Wisconsin in 1990 to determine the effect of overstory density and understory competition on the performance of bareroot and containerized northern red oak seedlings on a dry-mesic site. The relationship between seedling performance and the number of first-order lateral roots was also tested. Seedling performance was evaluated under three overstory densities—clearcut, 25%, and 50% crown covers—in combination with (or without) understory vegetation control with herbicide. Height growth was greater for containerized seedlings than for bareroot seedlings after two and three growing seasons. After 2 years, seedling growth was greatest in the sprayed clearcut plots, but was only slightly greater than the unsprayed plots under the 25% crown cover (bareroot 25.5 vs. 23.8 cm, and containerized 33.0 vs. 31.2 cm, respectively). After 3 years, seedling height growth (containerized and bareroot) was significantly greater in the unsprayed plots under the 25% crown cover than in all overstory/understory treatment combinations examined. These early results suggest that the light shelterwood (25% crown cover) treatment may be a good alternative over the more traditional management scheme of establishing seedlings under a medium density shelterwood (70% crown cover) with total overstory removal at a later date.

Developing an effective regeneration system is a key aspect of managing any tree species. The primary goal of an artificial regeneration system is to establish a vigorously growing seedling as economically as possible. To achieve this goal, conditions must be created through cultural practices and manipulation of the microenvironment to meet the biological needs of the species. In all cases, these systems should be viewed on a site-specific basis until the forest manager has the knowledge to generalize across site types.

Northern red oak (*Quercus rubra* L.) is one of the most valuable hardwood species in the Lake States. However, at present forest managers do not have reliable site-specific regeneration systems for red oak in the region. Successful regeneration systems have been developed for northern red oak in the central hardwoods region that include a one-or two-cut shelterwood, competition control, planting bareroot stock with a caliper of 9.5 mm (3/8 inch) or greater, followed by removal of the shelterwood after 3 years (Johnson et al. 1986). Traditionally, shelterwood systems that retain a crown cover of about 70% have been prescribed for regeneration of northern red oak. In fact, regeneration failures are predicted if the overstory is reduced to 50% crown cover or less (Sander 1979, Loftis 1983). In addition, Lorimer (1989) suggests that the sluggish growth habits of oak are responsible for regeneration failures with shelterwood management, and that any type of overstory reduction will only lead to the replacement of oak by other species. However, attempts at artificial regeneration of northern red oak with medium density shelterwood management (e.g., 70% crown cover) have failed in the upper Great Lakes region, probably because of use of poor planting stock, improper planting and handling practices, intense understory competition, inadequate site preparation, and insufficient light to support sustained growth during establishment phases.

---

[1] The authors are Biologist and Tree Physiologist, respectively, North Central Forest Experiment Station, USDA Forest Service, Rhinelander, WI 54501.

Planting stock of the size recommended by Johnson cannot be produced in a single year in northern nurseries, and 2-0 stock is more costly and often too large to be planted efficiently. Although there is some correlation between root collar diameter and field performance, there is growing evidence that the number of first-order lateral roots on a seedling may be a better predictor of field performance (Kormanik 1989). Recent modifications of nursery cultural practices have led to an increase in the overall seedling size and the number of first-order lateral roots on 1-0 northern red oak nursery stock (Buchschacher et al. 1991). However, production of 1-0 northern red oak in northern regions is still not up to the standards outlined by Johnson. Seedlings with at least six lateral roots are used successfully for regenerating northern red oak (Schultz and Thompson 1991), and seedlings with more lateral roots may permit the use of somewhat smaller stock than recommended by Johnson.

The growth potential of northern red oak is believed to be highest in full light conditions on rich mesic sites. Planting seedlings in such conditions usually requires herbicide applications to control competing vegetation. Environmental concerns have led to a reduction in the use of herbicide on some public lands, and control of vegetation by the use of herbicides may not be a viable management option in the future. Northern red oak also grows reasonably well on drier sites (i.e. dry-mesic) where understory competition is less intense. Kotar (1991) suggested that these sites may offer the best opportunities for oak regeneration in the Lake States. We conducted a study to develop an artificial regeneration system for northern red oak on dry-mesic sites in northern Wisconsin. Our study was designed to evaluate overstory density (i.e. crown cover), competition control, stock type, and the number of lateral roots on bareroot seedlings as components of the regeneration system.

MATERIALS AND METHODS

The study was conducted within a mixed northern hardwood stand consisting of predominately paper birch (*Betula papyrifera* Marsh.), red maple (*Acer rubrum* L.), and northern red oak on the American Legion State Forest near Lake Tomahawk in northern Oneida County, Wisconsin. The site is a moderately fertile, dry-mesic site with sandy loam soils and habitat type AVVib (Acer/ Vaccinium - Viburnum) according to Kotar et al. (1988). The site index for northern red oak is 18.6 m (61 ft) (at age 50). The study design is a randomized complete block with a split-plot arrangement of treatments. It consists of three 0.3-ha (0.75-acre) replications of each of three overstory densities—clearcut, 25% crown cover, and 50% crown cover,—and two levels of herbicide—sprayed and unsprayed (Figure 1). A 9.8 meter (32 ft) buffer area of the same overstory density surrounds each plot, making each unit area 0.57-ha.(1.4-acre). Harvesting was by whole tree skidding in January and February 1989 to minimize soil disturbance and residual slash on the site. Tables based on the relationship between tree diameter and crown area (Godman and Tubbs 1973) modified by G. Erdmann (unpublished) were used to mark trees to the prescribed crown cover. Glyphosate (Roundup[2]) herbicide was broadcast sprayed on half of each plot at a rate of 4.7 l/ha (2 qts/acre) in September 1989. The entire study area was enclosed by a high tensile electric fence to minimize the impact of deer browse.

---

[2] The mention of trade names is for the information of the reader and does not constitute endorsement by the U.S. Department of Agriculture, Forest Service.

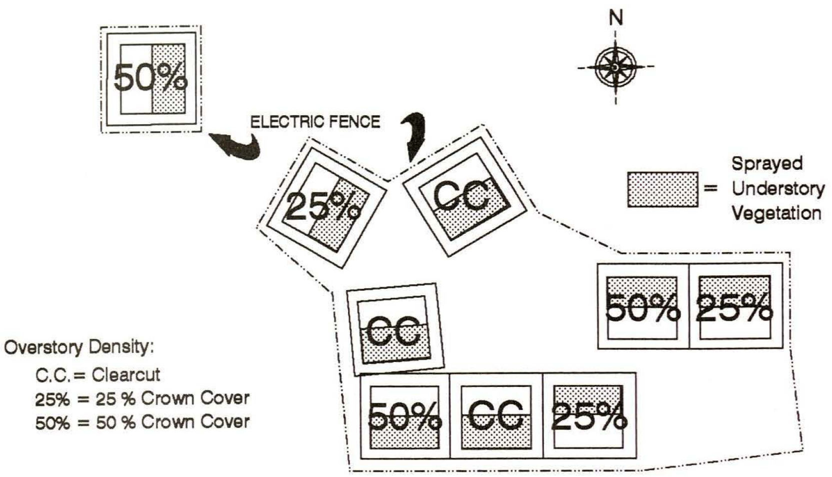


Figure 1.—Overview of Bird Lake oak regeneration site. Each overstory treatment plot is 0.75 acre with a 32 ft. buffer strip around the perimeter.

In May 1990, seedlings were planted within the study area for two separate experiments. In one experiment, we compared the responses of bareroot versus containerized seedlings among the overstory density and herbicide spray treatments. The bareroot seedlings had at least 10 permanent first-order lateral roots (roots > 1 mm in diameter at the point of attachment to the taproot), a minimum stem height of 13.0 cm, and caliper of 7.0 mm These seedlings had an average height of 31.5 cm and average caliper of 7.6 mm (Table 1). The containerized seedlings were grown in 10 x 36 cm (4 x 14 in) 4-ml polyethylene pots in the greenhouse for one-year. The containerized seedlings had a minimum 20 cm stem height and 3.8 mm caliper, and averaged 29 cm in height and 5.7 mm in caliper.

In the second experiment, seedling performance was compared by root-grade (i.e. the number of lateral roots > 1 mm in diameter). The seedlings were graded as follows: grade 1, 0 to 5 lateral roots; grade 2, 6 to 10; grade 3, 11 to 15; grade 4, 16 to 20; and grade 5, more than 20 laterals. The root-graded seedlings had a minimum stem height of 8 cm and caliper of 3.9 mm and averaged 21 cm in height and 6.0 mm in caliper (Table 1).

All seedlings were planted in 10-cm-diameter augered holes. The study included 48 bareroot, 12 containerized, and 35 root-graded seedlings (i.e. 5 grades x 7 seedlings/grade) in each overstory x spray treatment plot, for a total of 1710 seedlings in the study.

Seedling performance is reported here for 2 and 3 years after planting. Height growth is expressed as 2-year cumulative growth (seedling height after 2 years minus planting height), and third-year growth (the difference between total seedling height after 2 and 3 years). Some seedlings had a negative net growth in the third year because of partial dieback. The negative growth values for these seedlings were included for analysis, but seedlings that died back to the ground and did not resprout were excluded. Statistical analysis was by analysis of variance for split-plot designs with SAS (1988).

Table 1.—Mean establishment height and caliper of bareroot, containerized, and root-graded seedlings.

	Height (cm) Mean ± SE	Caliper (mm) Mean ± SE
Bareroot[a]	31.5 ± 0.31	7.6 ± 0.03
Containerized	29.1 ± 0.32	5.7 ± 0.04
Root graded[b]	21.1 ± 0.32	6.0 ± 0.04

[a] Bareroot seedlings had a minimum of 10 lateral roots > 1 mm diameter

[b] Root grades:
1 = 0-5 laterals > 1 mm
2 = 6-10 laterals > 1 mm
3 = 11-15 laterals > 1 mm
4 = 16-20 laterals > 1 mm
5 = > 20 laterals > 1 mm

RESULTS AND DISCUSSION

Survival

Overall, seedling survival was high throughout the study, reflecting the benefit of planting high quality stock. After 2 years, average survival ranged from 98% for the containerized seedlings to 99% for the bareroot seedlings. After 3 years, survival ranged from 94% for the containerized seedlings to 98% for the bareroot seedlings. Specifically, the 3-year survival for the bareroot seedlings ranged from 95% in the unsprayed clearcut plots to more than 99% in the unsprayed, 50% crown cover plots. The survival range for containerized seedlings was from 86% in unsprayed, 25% crown cover plots to 100% in sprayed, 50% crown cover plots.

Seedling Performance

Containerized vs Bareroot Seedlings

Containerized seedlings had much better height growth than bareroot seedlings after two and three growing seasons. After two growing seasons, growth of both seedling types was significantly greater in the clearcut and 25% crown cover plots than in the 50% crown cover plots (Figure 2). However, in the third year, performance declined in the clearcut plots for both types of seedlings. The best growth for both bareroot and container stock occurred in the unsprayed, 25% crown cover plots. The containerized seedlings grew more than the bareroot seedlings even though the average height of the containerized seedlings at establishment was less than that of the bareroot seedlings (29.1 cm vs. 31.5 cm, respectively) (Table 1).

Containerized Seedlings

Two-year cumulative growth of containerized seedlings was greatest in the sprayed clearcut plots, but not significantly greater than in the unsprayed 25% crown cover plots. Growth was significantly less but statistically equal in all other overstory density/spray treatment combinations, except in the sprayed 50% crown cover plots where growth was the poorest (Figure 3). After three growing seasons, containerized seedling growth was greatest in the unsprayed 25% crown cover plots, and statistically less in all other treatment plots. Net growth was negative in unsprayed clearcut plots.

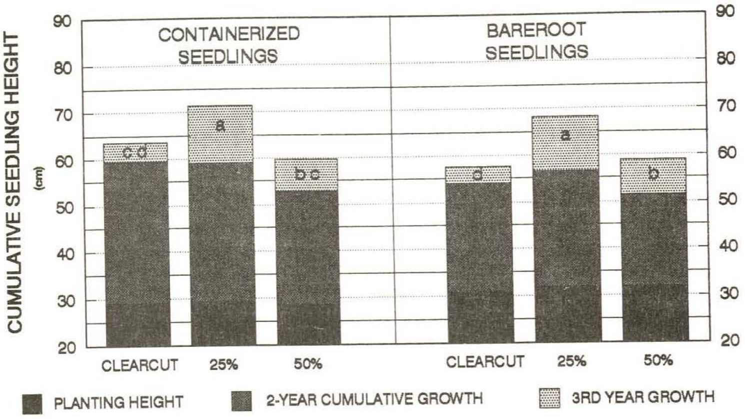


Figure 2. —Cumulative seedling height at planting date and after two and three growing seasons for containerized and bareroot seedlings growing under three overstory densities (clearcut, 25% crown cover, and 50% crowncover). Growth segments labeled with the same letter are not significantly different for the respective growth periods. (P=0.05)

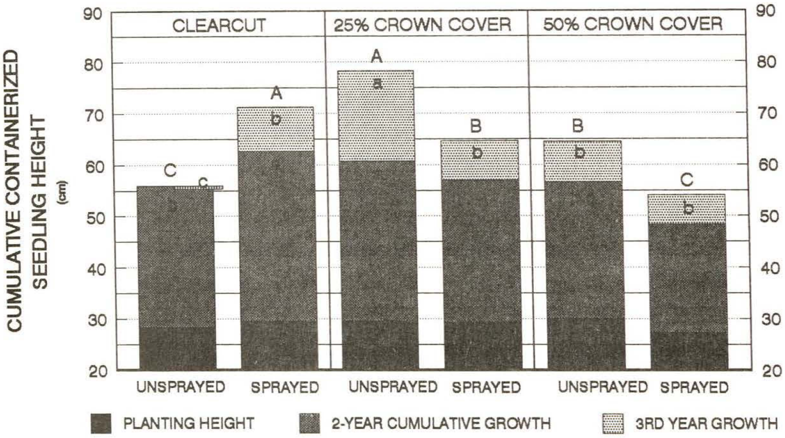


Figure 3.—Cumulative height of containerized seedlings at planting date and after two and three growing seasons relative to overstory density and herbicide spray treatments. Growth segments labeled with the same letter are not significantly different for the respective growth periods. Capital letters represent significant differences in total seedling height after 3 years. (P=0.05)

We believe the reduced growth in the clearcut can be attributed to rapid invasion of competing vegetation and to seedling dieback caused by a late spring frost in 1992. Herbicide spraying temporarily reduced the density of competing vegetation in the clearcut in the first 2 years, but the vegetation redeveloped rapidly in the third growing season, causing interference and reducing availability of resources for oak seedling growth. The frost damage, although not extensive, occurred only in the clearcut plots and not in any of the shelterwood plots. Similar frost damage occurred at another study site approximately 32 km (20 miles) west of this site; 100% of the seedlings in an 8-ha (20 acre) clearcut were severely damaged by frost, but there was no damage in adjacent shelterwoods of 50% crown cover and 75% crown cover.

Bareroot Seedlings

Bareroot seedling performance was relatively uniform for the first two growing seasons, with only slightly better growth (although statistically significant) in the sprayed clearcut, and both sprayed and unsprayed 25% crown cover plots (Figure 4). During the third growing season, more dramatic treatment differences appeared. The greatest seedling growth was under the 25% crown cover, where growth was statistically greater in the unsprayed plots than in the sprayed. Growth was significantly less in the other overstory/understory treatment plots, with the poorest growth in the unsprayed clearcut plots.

The single condition that is consistent with "best" seedling growth for both types of seedlings after two and three growing seasons, is the unsprayed 25% crown cover. Seedling growth was similar in the sprayed clearcut plots after two years, but declined in the third year (1992). As mentioned previously, a June, 1992 frost caused considerable damage to seedlings on this and other sites in northern Wisconsin, and certainly contributed to the reduction in growth in these plots. Because there was not a significant difference in growth (for both type of seedlings) between the sprayed and unsprayed treatments in the 50% crown cover plots, it appears that the more dense overstory

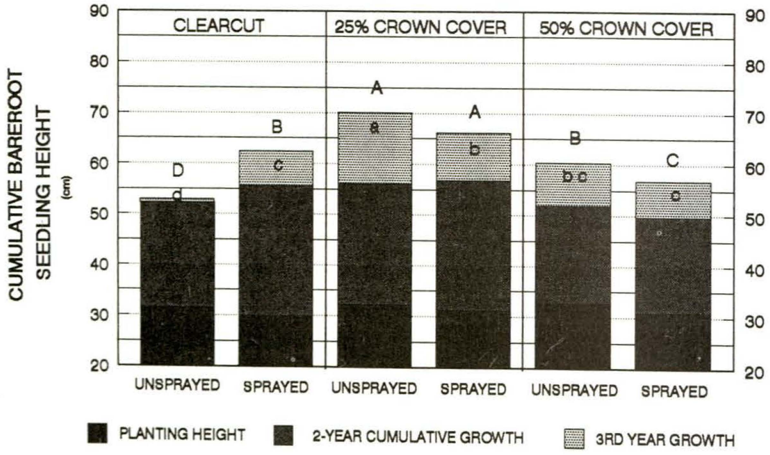


Figure 4.—Cumulative height for bareroot seedlings at planting date and after two and three growing seasons relative to overstory density and herbicide spray treatments. Growth segments labeled with the same letter are not significantly different for the respective growth periods. Capital letters represent significant differences in total seedling height after 3 years. (P=0.05)

is having an overriding influence on light and other resource availability. The herbicide treatment apparently did not provide a benefit to seedling growth under the 25% overstory density on these sites as we expected. This trend, although examined here at an early stage in regeneration, is an especially important finding considering the recent concerns on the use of herbicides. It also illustrates the benefit of selecting sites with a habitat where understory competition is minimal, and conditions are adequate for sustained oak growth. These findings lead us to conclude that although the seedlings grow well in the sprayed clearcut plots, the "best" overall treatment for sustained seedling growth on this habitat type is a 25% crown cover shelterwood, with an unsprayed understory.

After three growing seasons, the poorest growth and most dieback and mortality in the 25% crown cover plots occurred in close proximity to stump sprouts that over-shadowed some planted seedlings. This reduction in growth and incidence of mortality is likely attributed to the micro-environment created by the stump sprouts and reduces the growth potential of the overall environment of the 25% crown cover treatment. Therefore, seedlings should not be planted in close proximity to stumps that are likely to sprout vigorously after harvesting. Studies are planned to quantify the light environment relative to the overstory density and lower canopy composition to better evaluate seedling performance in specific microenvironments. In the future, "best growth" is expected to be in the unsprayed 25% crown cover plots. Thus far the seedlings in those plots have grown to be the tallest in the study, and even greater growth is expected from the larger, well established seedlings.

ROOT-GRADED SEEDLINGS

We included root-graded seedlings in this study to test the hypothesis that the number of first-order lateral roots is correlated with field performance (Kormanik 1989). Two-year growth data pooled from all overstory/understory plots showed that grade 5 seedlings (seedlings with more than 20 lateral roots) grew an average 23.5 cm but there was no significant difference between grade 5 seedlings and grade 4 seedlings (x=21.5 cm). Grade 3 seedlings averaged 18.8 cm after two growing seasons, and grade 2 seedlings averaged 18.0 cm. However, there was no significant difference in two-year height growth among root grade 2, 3, and 4 seedlings. Grade 1 seedlings, with an average 2-year height growth of 12.5 cm, grew significantly less than all other root-graded seedlings (Figure 5). When seedling performance was analyzed relative to overstory density, 2-year

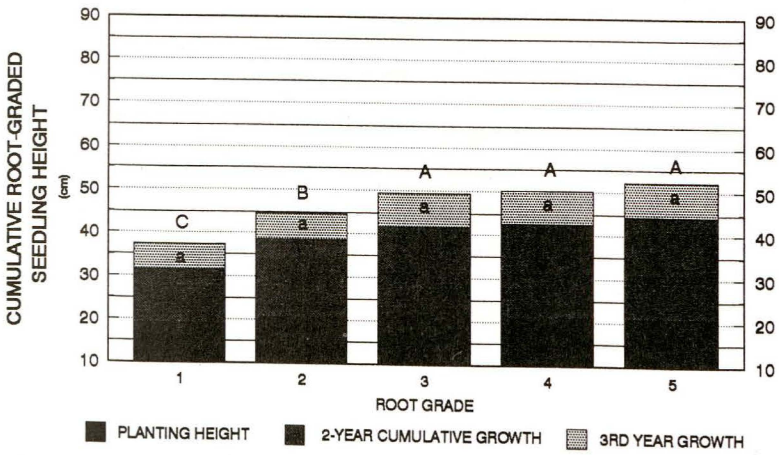


Figure 5.—Cumulative seedling height at planting date and after two and three growing seasons relative to root grade. Growth segments labeled with the same letter are not significantly different for the respective growth periods. Capital letters represent significant differences in total seedling height after 3 years. (P=0.05)

Table 2.—Average cumulative 2-year height growth ± SE (centimeters) for root-graded seedlings relative to overstory density.

Overstory density	**Root grade** **1**	**2**	**3**	**4**	**5**
Clearcut	16.8 ± 2.9	18.8 ± 1.9	20.3 ± 2.3	25.4 ± 1.8	22.8 ± 2.4
25% Crown cover	11.5 ± 2.9	20.2 ± 2.4	20.8 ± 1.6	21.1 ± 2.1	26.0 ± 2.2
50% Crown cover	9.7 ± 1.9	14.7 ± 1.6	15.3 ± 1.5	17.6 ± 1.0	21.4 ± 2.0

Table 3.—Average third-year height growth ± SE (centimeters) for root-graded seedlings relative to overstory density.

Overstory density	**Root grade** **1**	**2**	**3**	**4**	**5**
Clearcut	2.4 ± 4.5	2.2 ± 3.0	6.4 ± 2.0	5.0 ± 2.4	7.9 ± 2.2
25% Crown cover	7.3 ± 3.0	9.7 ± 2.4	8.7 ± 1.5	11.1 ± 2.2	8.7 ± 2.7
50% Crown cover	7.0 ± 1.5	5.6 ± 1.5	8.3 ± 1.5	7.0 ± 1.4	7.2 ± 1.8

cumulative height growth was poorest under the 50% crown cover for all root grades. We found that the higher grade seedlings performed better than the lower grade seedlings in all overstory densities (Table 2). Root grade made little difference in third-year seedling height growth (Table 3). Total height of the seedlings after 3 years was significantly greater for root grades 3 to 5 than for root grades 1 and 2, largely because of differences in growth during the first 2 years (Figure 5).

Although the use of 2-0 seedlings with a minimum caliper of 9.5 mm (3/8 inch) (Johnson et al. 1986) surely has merit, our study shows that smaller caliper seedlings can be successfully used in regeneration plantings if the seedlings have a significant number of first-order lateral roots. In the Lake States, large 2-0 nursery stock are not often used for artificial regeneration because of increased nursery costs associated with production, handling and shipping, and because of the belief that larger stock is more difficult to plant properly. This study illustrates the feasibility of using 1-0 nursery stock when essential criteria are met. The quality of the seedlings must meet minimum standards based on performance in the field. For this study, the bareroot seedlings had at least 10 first-order lateral roots greater than 1 mm in diameter and height of at least 13 cm and caliper of 7.0 mm. Although nurseries in the northern Lake States can produce 1-0 seedlings that meet these minimum standards, the percentage of cull seedlings in the seed bed is usually too high with standard nursery practices. However, with the utilization of quality seed sown at bed densities no greater than 85 per square meter (8 per square foot) and multiple applications of fertilizer at low rates (Teclaw and Isebrands 1991), seedling uniformity and quality can be improved dramatically, and a high percentage of 1-0 northern red oak seedlings can be produced that meet high quality standards.

SUMMARY

Our studies of artificial oak regeneration in the Lake States show that it must be viewed as a regeneration system, with the goal of obtaining an established, vigorous, free-to-grow seedling. The system that produces this seedling begins with the collection of high quality acorns and includes many steps—any of which may affect achieving the ultimate goal. Our early results suggest that the use of high quality seedlings, planted on dry-mesic sites, under a light overstory afford good conditions for the establishment of northern red oak without the use of herbicides. Our results also support Kotar's (1991) premise that dry-mesic sites are good sites on which to regenerate and grow northern red oak. Although regeneration systems that include clearcutting or two-cut shelterwoods may succeed in artificially regenerating oak in some regions, the species composition and its response to shelterwood management often differ by regions, suggesting that these methods cannot be universally applied. Moreover, the high probability of dieback due to late spring/early summer frosts in the Lake States may alone make artificial regeneration in clearcuts less successful in this region.

Although we now recommend high quality bareroot seedlings as the primary stock type for planting, our results suggest that containerized northern red oak seedlings merit future consideration. At present, production costs are high for containerized seedlings, but under the conditions of this study containerized seedlings outperformed bareroot seedlings over a 3-year period. Comparative studies on above and below ground morphology and carbohydrate reserves of bareroot and containerized seedlings need to be conducted to help us understand why the two types of seedlings perform differently.

In this paper we have outlined a successful artificial regeneration system for northern red oak on dry-mesic sites in the Lake States, based on 3-year results. The system departs from traditional methods in this region that use medium density shelterwoods and chemical control of competing vegetation to establish seedlings and total overstory removal at a later date for sustained growth. Our preliminary results suggest that on dry-mesic sites, light shelterwood cuts without herbicide spraying, and planting high quality nursery stock may be a successful alternative artificial regeneration system for forest managers to consider.

LITERATURE CITED

Buchschacher, G.L., P.T. Tomlinson, P.S. Johnson, and J.G. Isebrands. 1991. Effects ofseed source and cultural practices on emergence and seedling quality of northern red oak nursery stock. P. 126-130 in Proc. Sixth Biennial Southern Silvicultural Research Conf. Gen. Tech. Rep. SE-70.

Godman, R.M., and C.H. Tubbs. 1973. Establishing even-age northern hardwood regeneration bythe shelterwood method - a preliminary guide. USDA For. Serv. Res. Pap. NC-99, 9 p.

Johnson, P.S., C.D. Dale, K.R. Davidson, and J.R. Law. 1986. Planting northern red oak in theMissouri Ozarks: a prescription. North. J. Appl. For. 3:66-68.

Kormanik, P.P. 1989. Importance of first-order lateral roots in the early development of forest treeseedlings. P. 157-169 in Proc. Interrelationships between microorganisms and plants in soil, Vancura, V., and F. Kunc (eds.). Czechoslovak Academy of Sciences, Prague, Czechoslovakia.

Kotar, J. 1991. Importance of ecological classification in oak management. P. 132-140 in Proc. Theoak resource in the upper midwest: implications for management, Laursen, S.B., and J.F. DeBoe (eds.). Minn. Ext. Serv., Univ. of Minn., St. Paul.

Kotar, J., J.A. Kovach, and C.T. Locey. 1988. Field guide to forest habitat types of northernWisconsin. Dept. of For., Univ. of Wis. Madison and Wis. Dept. of Nat. Res., 212 p.

Loftis, D.L. 1983. Regenerating southern Appalachian mixed hardwood stands with the shelterwoodmethod. South. J. Appl. For. 7:212-217.

Lorimer, C.G. 1989. The oak regeneration problem: new evidence on cause and possible solutions.For. Res. Anal. No. 8. Dept. of For., Univ. of Wis. Madison, 31 p.

SAS Institute, Inc. 1988. SAS/STAT User's Guide. Release 6.03 Edition, Cary, NC,1028 pp.

Sander, I.L. 1979. Regenerating oaks with the shelterwood system. P. 54-60 in Proc. Regenerating oaks in upland hardwood forests. The 1979 John S. Wright Forestry Conference, Holt, H.A., and B.C. Fischer (eds.). Purdue Univ., West Lafayette, IN.

Schultz, R.C. and J.R. Thompson. 1991. The quality of oak seedlings needed for successfulartificial regeneration in the central states. P. 180-186 in Proc. The oak resource in the upper midwest: implications for management, Laursen, S.B. and J.F. DeBoe (eds.). Minn. Ext. Serv., Univ. of Minn., St. Paul, MN.

Teclaw, R.M. and J.G. Isebrands. 1991. Artificial regeneration of northern red oak in the LakeStates. P. 187-197 in Proc. The oak resource in the upper midwest: implications for management, Laursen, S.B., and J.F. DeBoe (eds.). Minn. Ext. Serv., Univ. of Minn., St. Paul, MN.

ACKNOWLEDGMENTS

The authors acknowledge the support of the Nicolet, Chequamegon, and Ottawa National Forests, the Wisconsin Department of Natural Resources, Bureaus of Forestry and Wildlife and Packaging Corporation of America. Special thanks to John C. Zasada for his invaluable help and contributions to the paper. The authors also want to thank Trenton Marty, Richard Cutler, Terry Strong and an anonymous reviewer for their timely comments on an earlier draft.

Survival and Growth for the First-growing Season of Northern Red Oak (*Quercus rubra* L.) Seedlings Underplanted in Mixed Upland Hardwood Stands in South Central Iowa[1]

Robert E. Bardon and David W. Countryman[2]

Abstract: This paper reports the first year survival and growth of red oak seedlings underplanted in two mixed upland hardwood stands in south central Iowa. The underplanted seedlings were undercut and not undercut 1-0 red oak stock.

Fifteen blocks were laid out in 1990, with seven of the blocks receiving a foliar application of glyphosate herbicide. In the winter of 1990-1991, all non-oak trees were removed and their stumps treated with Picloram.

Treatment areas were established in the spring (1991). The trials encompassed ten seedlings from each of three root classes: 0-4, 5-9, and ten or more permanent, first-order, lateral roots greater than 1 mm. The seedlings were planted in randomly assigned rows. Tree shelters were randomly assigned to the first five or second five seedlings in each row.

The first growing season data show that spraying, tree shelters, and the number of lateral roots seem to be important in the establishment of red oak seedlings. Spraying was significant at reducing competition by 42%. Seedlings planted in tree shelters outperformed seedlings without tree shelters in average height growth (128%) and survival (7%). Seedlings with ten or more lateral roots had better average height growth than did seedlings with 0-4 (369%) and 5-9 (70%) lateral roots. The first growing season had 78% survival or better for all seedlings.

INTRODUCTION

A recent concern in the management of northern red oak (*Quercus rubra* L.) is the difficulty in regenerating new stands to replace those harvested (Holt and Fisher 1979, Johnson *et al.* 1984, Crow 1988, Lorimer 1989). The difficulty in regenerating red oak stands is that many oak forests in parts of Eastern and Central United States have developed dense understories of shade-tolerant species (Schlesinger 1976, Ehrenfeld 1980, Coder 1985). Thus, as red oak stands are harvested, they gradually convert to sugar maple (*Acer saccharum* Marsh.), American basswood (*Tilia*

---

[1] Journal Paper No. J-15175 of the Iowa Agriculture and Home Economics Experiment Station, Ames, Iowa. Project No. 2172. Partial funding for this research was obtained from the Leopold Center for Sustainable Agriculture and the Forestry Division of Iowa Department of Natural Resources.

[2] The authors are, respectively, Research Assistant and Professor, Department of Forestry, Iowa State University, Ames, Iowa 50011.

americana L.), American elm (*Ulmus americana* L.), and white ash (*Fraxinus americana* L.) because there is little or no advanced red oak reproduction (Sander 1977).

If no artificial regeneration is used, the percentage of red oak in the succeeding rotation is directly related to the amount of red oak reproduction present before final harvesting takes place. While stump sprouts can be anticipated, oak's ability to sprout decreases with age. Only 30% of northern red oak stumps are expected to sprout after they reach 43 cm in diameter (Sander 1977). Therefore, seedlings must be established to regenerate the new stand, because sprouts can not be depended on. This reproduction must be established over a period of time, either by natural or artificial regeneration before the mature overstory trees are harvested (Carvell 1979).

Sander *et al.* (1984) demonstrated in the Missouri Ozarks that red oak seedlings must be at least 1.5 m high or 2.5 cm in ground-line diameter to have the potential for reaching dominance in a new stand. It may take 10 to 20 years before an adequate amount of oak regeneration reaches these minimum sizes so that the overstory can be removed (Sander 1977). Such sluggish growth in red oak seedlings allows them to be overtopped by the competition at an early age and seems to be the primary reason for red oak regeneration failures (Johnson and Jacobs 1988, Kolb and Steiner 1989, Lorimer 1989).

Northern red oak seedlings have the capacity to grow rapidly because of their ability to have multiple flushes under optimal conditions. However, when stressed, as is typical in the field, red oak tends to have conservative shoot growth and allocates more photosynthate to root growth (Kolb and Steiner 1990). When red oak has a flush, it involves four distinct growth phases. The growth phases are lag phase (leaves fully expanded), bud phase (bud swell), stem linear phase (linear stem growth), and leaf linear phase (linear leaf growth). The lag phase is when root growth occurs (Dickson 1991).

Research, by Sander in the 1960's and 1970's developed the guidelines for establishing red oak regeneration. These guidelines state that 1,200 - 1,500 red oak seedlings/hectare at 1.5 m in height are needed to establish a pole stand containing 30% oak (Lorimer 1989). Obviously, very few stands located on average or good sites could even come close to Sander's guidelines for red oak regeneration (Lorimer 1989).

Current research is focused on finding ways to establish successfully red oak regeneration. Researchers are focused on: planting improved nursery stock, using tree shelters, herbicide control of competition, removal of understory and overstory vegetation, and combinations of these methods (Johnson 1976, Johnson 1981, Loftis 1985, Tuley 1985, Johnson *et al.* 1989, Potter 1991, Schultz and Thompson 1991, Teclaw and Isebrands 1991, Minter *et al.* 1992.)

STUDY OBJECTIVE

The objective of this study is to evaluate survival and growth of underplanted northern red oak seedlings in south central Iowa. This paper reports the results from the first year of the study.

STUDY AREA

The study is located in Lucas County in south central Iowa. The study was conducted in two upland, mixed, hardwood stands of 2.3 ha each. The stands are located on the McNay Research Farm and the Stephens State Forest.

Normal amount of annual precipitation in Lucas County is 88.42 cm. Annual precipitation for the establishment year, however, was 90.73 cm (NOAA 1991). Although the annual precipitation for the establishment year was 2.31 cm above normal, precipitation during the growing season, from June to September, was below normal (range from 3.76 cm to 8.05 cm below normal).

McNay Site

The McNay stand has a past history of grazing, which was abandoned approximately 15-20 years ago. Based on an initial inventory, the site index (base age = 50) was 20 m (s = 6) ("s" = standard deviation), with an average stocking level of 21.5 m^2/ha (s = 3). Based on findings of Gingrich (1971), the stand was 100% stocked. After cutting all non-oak trees greater than 2.54 cm in diameter at breast height (dbh), the average stocking level was reduced to 48% or 14.1 m^2/ha (s = 2.3).

Before cutting, the McNay stand had 1,565 trees/ha (s = 395) with an average dbh of 9.4 cm (Figure 1). The McNay site was regenerating to elm (*Ulmus* species) (1,726 seedlings /ha, s = 321), white oak (*Quercus alba* L.) (549 seedlings/ha, s = 124), ironwood (*Ostrya virginiana* (Mill.) K. Koch) (314 seedlings/ha, s = 74), and northern red oak, hackberry (*Celtis occidentalis* L.), and prickly ash (*Zanthoxylum americanum* Mill.) (235 seedlings/ha, s = 50). After all non-oak trees greater than 2.54 cm at dbh were cut, the stand had 95 trees/ha (s = 8.6), with an average dbh of 43.4 cm (Figure 1). Figure 2 presents a distribution of average basal area (m^2/ha) by 5 cm diameter classes for oak trees left on McNay and non-oak trees removed from McNay.

The soil types for McNay are gara and armstrong loams, which originated from glacial till parent material. Gara loam occupies 90% of the stand, and armstrong loam occupies 10% of the stand (Fenton 1992).

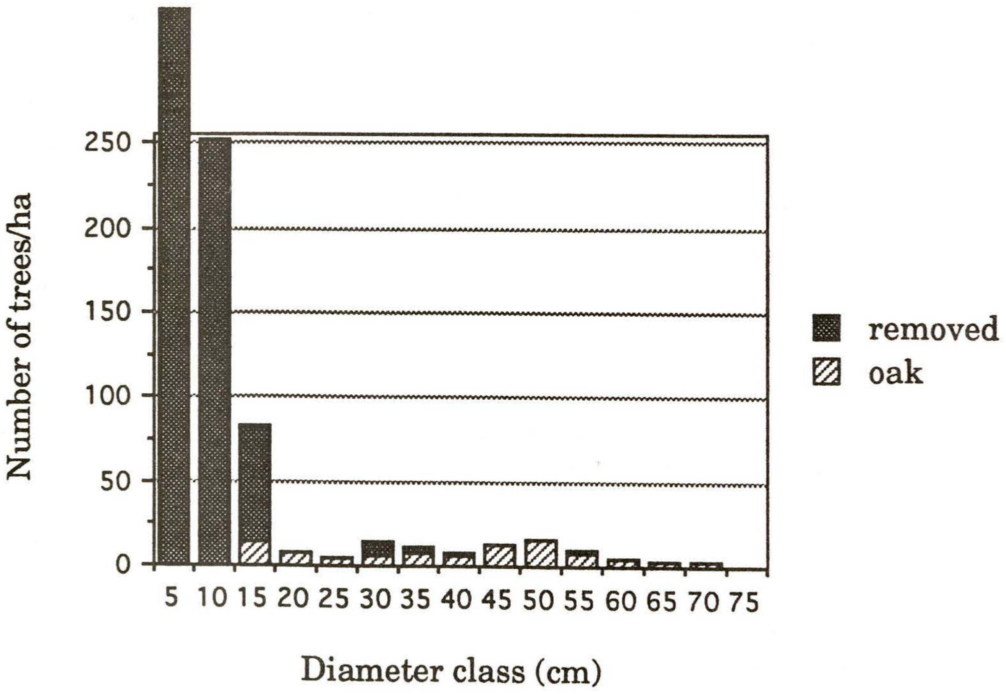


Figure 1.— Average number of trees/hectare by 5 cm diameter classes for oak trees left on McNay and non-oak trees removed from McNay.

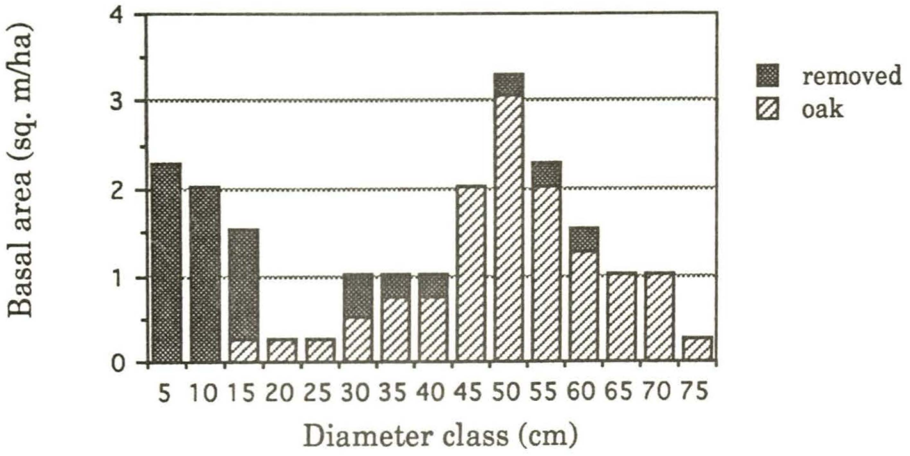


Figure 2.—Average basal area (m²/ha) by 5 cm diameter classes for oak trees left on McNay and non-oak trees removed from McNay.

Stephens Site

Based on an initial tree inventory, the site index (base age = 50) for Stephens was 20 m (s = 6) with an average stocking level of 19.2 m²/ha (s = 1.4). Based on Gingrich (1971), the stand was 75% stocked. After cutting all non-oak trees greater than 2.54 cm at dbh, the average stocking level was reduced to 60% or 15.9 sq. m./ha (s = 1.7).

Before cutting, the Stephens stand had 578 trees/ha (s = 118) with an average dbh of 18.7 cm (Figure 3). The stand was regenerating to dogwood (*Cornus* species) (2,236 seedlings/ha, s = 1,038), elm (1235 seedlings/ha, s = 244), white oak (882 seedlings/ha, s = 183), red oak (530 seedlings/ha, s = 183), hickory (*Carya* species), black cherry (*Prunus serotina* Ehrh.) (118 seedlings/ha, s = 37), and hackberry (59 seedlings/ha, s = 18.3) After cutting all non-oak trees greater than 2.54 cm dbh, the stand had 282 trees/ha (s = 43) with an average dbh of 26.7 cm (Figure 3). Figure 4 presents a distribution of average basal area (m²/ha) by 5 cm diameter classes for oak trees left on Stephens and non-oak trees removed from Stephens.

The soil types for Stephens are welter silt, lindley, and keswick loams (Fenton 1992). The welter silt loam originated from loess parent material and occupies 55% of the stand. Lindley and keswick loams originated from glacial till parent material, and occupy 35% and 10% of the stand, respectively.

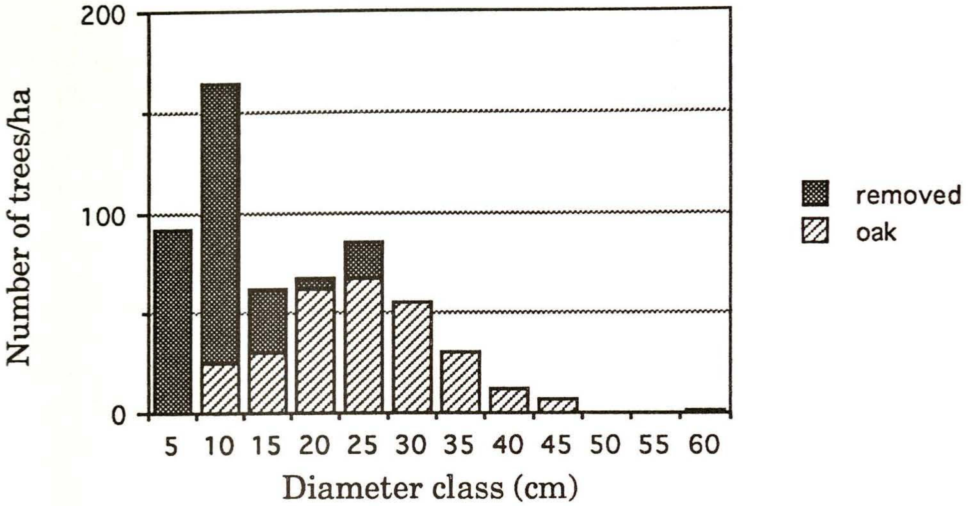


Figure 3.—Average number of trees/ha by 5 cm diameter classes for oak trees left on Stephens and non-oak trees removed from Stephens.

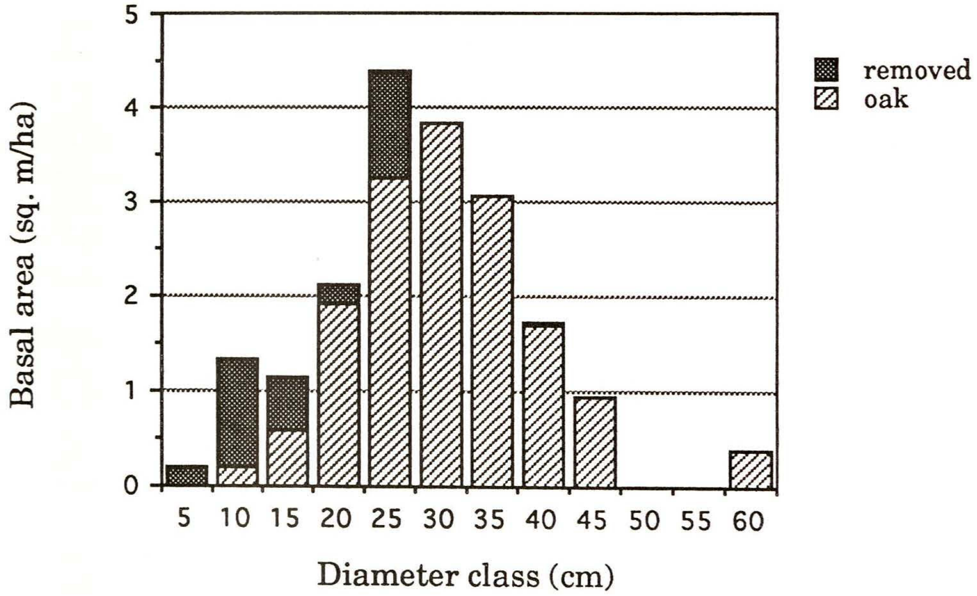


Figure 4.—Average basal area (m^2/ha) by 5 cm diameter classes for oak trees left on Stephens and non-oak trees removed from Stephens.

METHODS

Fifteen square blocks, 46 meters on each side, were laid out in August 1990 at McNay and Stephens (Figure 5). Glyphosate herbicide was applied in August 1990 to four randomly selected blocks on McNay and three randomly selected blocks on Stephens. A foliar application of glyphosate herbicide was applied to kill material less than 2.54 cm in diameter at 1.4 m above the ground. In the winter of 1990-91, all non-oak trees greater than 2.54 cm at 1.4 m above the ground were removed, and the stumps of those trees were treated with picloram.

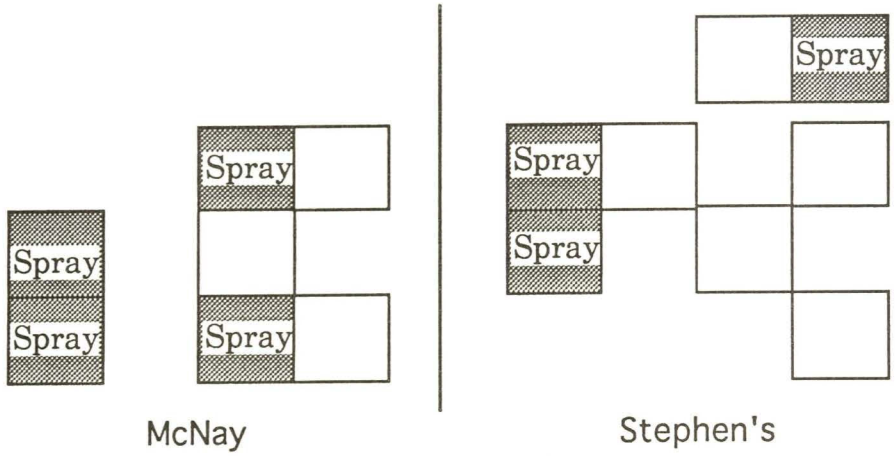


Figure 5.—Layout of blocks for each study area

After removal of non-oak trees, treatment areas were established during the spring of 1991. In each treatment area to be underplanted, 30 seedlings were planted in 3 rows of 10 seedlings per row at a spacing of 1.2 m between seedlings and 3 m between rows. Seedlings underplanted in half of the treatment areas had been undercut in the nursery, and the seedlings planted in the other half of the treatment areas had not been undercut.

Before underplanting, the undercut and not-undercut seedlings were graded by the number of permanent, first-order, lateral roots greater than 1 mm in basal diameter at the tap root. The seedlings were separated into the following root number classes: 0-4, 5-9, and 10 or more permanent, first-order, lateral roots greater than 1 mm. Permanent, first-order, lateral roots greater than 1 mm that originated from the callus wound area of undercut seedlings were also included in meeting the grading criteria.

As the seedlings were being graded, they were assigned a color coded numbered tag to keep track of each seedling. Initial height of each seedling was measured from the root collar to the tip of the terminal bud on the main leader, and initial caliper was measured just above the root collar.

Once the seedlings were underplanted, white tree shelters[3] that were four feet tall were randomly assigned to the first five seedlings or the second five seedlings in each row. White tree shelters were chosen, instead of the standard brown tree shelters, because of the lower level of light in the understory. Tree shelters were placed on the seedlings at the time of planting. The height and caliper at ground level of each seedling was recorded in the fall of 1991.

---

[3] The brand of tree shelters used was Tubex. Tubex was chosen based on its availability; this choice does not imply endorsement of this specific brand.

Competition was observed on mil-acre plots (0.0004 ha). A mil-acre plot was established at 3.8, 7.6, and 11.4 m along a transect in the middle of each treatment area. The mil-acre plots coincide with the middle planting row in each treatment. In each mil-acre plot the species, height, caliper at ground level of each stem less than 10 cm in diameter, and overstory basal area (live and dead) were recorded. The number of new competing seedlings was determined by the number of seedlings less than 4 mm in diameter at ground-line.

Data were collected on August 6-8, September 10-12, and September 24-26, 1991. The data covers first-growing season survival and height growth of northern red oak seedlings from planted 1-0 nursery stock seedlings and the competition with which the red oak seedlings had to contend. Because treatments had unequal sample sizes, statistical analyses were done using methods of least squares to fit general linear models (SAS Institute Inc. 1988). McNay and Stephens data were combined, because statistical analysis showed that location was not significant.

RESULTS

Underplanted Seedling Performance

Survival

The best seedling survival at the end of the first-growing season (1991) was 95% for seedlings with 10 or more first-order, lateral roots greater than 1 mm, and that were protected by tree shelters. The lowest percentage of survival was 78% for seedlings with 0-4 first-order, lateral roots, greater than 1 mm, and that were planted without tree shelters (Table 1) (Pr>F = 0.07). Seedlings protected by tree shelters had an average of 93% survival compared with 86% survival of seedlings without tree shelters (Table 2) (Pr>F = 0.006). Whether or not seedlings were undercut (Pr>F = 0.81) and whether or not the area was sprayed (Pr>F = 0.37) before planting did not make a statistically significant difference in survival.

Initial height

Average initial heights for seedlings that were undercut in the nursery were significantly greater than seedlings that were not undercut in the nursery (Table 3) (Pr>F = 0.0004).

Table 1.—Percentage of survival of underplanted 1-0 northern red oak seedlings by root class with and without tree shelters

Root class	Tree shelters	Survival (%)	Standard error of the mean	Sample size
0-4	tree shelters	92	2.4	89
0-4	no tree shelters	78	3.8	95
5-9	tree shelters	90	2.7	92
5-9	no tree shelters	90	2.5	98
10 or more	tree shelters	95	2.1	97
10 or more	no tree shelters	90	2.6	98

Table 2.—Percentage of survival of underplanted 1-0 northern red oak seedlings with and without tree shelters

Tree shelters	Survival (%)	Standard error of the mean	Sample size
tree shelters	93	1.4	278
no tree shelters	86	1.8	291

Table 3.—Average initial seedling heights, before underplanting, for 1-0 northern red oak undercut and not-undercut seedlings in the nursery

	Initial height	Standard error of the mean	Sample size
Not undercut	24.1 cm	0.67	15
Undercut	18.9 cm	0.54	15

Height growth

The greatest average height growth (7.5 cm) (Table 4) was for seedlings with 10 or more first-order, lateral roots greater than 1 mm (Pr>F = 0.0001). Undercut seedlings with 0-4 permanent, first-order, lateral roots had greater height growth than not-undercut seedlings. However, undercut seedlings with five or more permanent, first-order, lateral roots had less average height growth than not-undercut seedlings (Table 5) (Pr>F = 0.01).

Average height growth was also greatest for seedlings protected by tree shelters (Table 6) (Pr>F = 0.0001). Seedlings protected by tree shelters averaged 6.4 cm in height growth compared with seedlings without tree shelters, which averaged 2.8 cm of height growth.

Whether or not the area was sprayed before planting (Pr>F = 0.17) did not make a statistically significant difference in average height growth.

Table 4.—Average height growth (cm) for each root class of underplanted 1-0 northern red oak seedlings

Root class	Avg ht. growth (cm)	Standard error of the mean	Sample size
0-4	1.6	0.74	184
5-9	4.4	0.78	190
10 or more	7.5	0.70	195

Table 5.—Average height growth (cm) for each root class of 1-0 northern red oak seedlings undercut and not undercut in the nursery

Root class	**Undercut**	**Avg ht. growth (cm)**	**Standard error of the mean**	**Sample size**
0-4	not undercut	0.3 cm	1.28	94
0-4	undercut	2.9 cm	0.71	90
5-9	not undercut	5.1 cm	1.20	101
5-9	undercut	3.6 cm	0.97	89
10 or more	not undercut	9.2 cm	0.92	94
10 or more	undercut	6.0 cm	1.03	101

Table 6.—Average height growth (cm) for underplanted 1-0 northern red oak seedlings with and without tree shelters

Tree shelters	**Avg ht. growth**	**Standard error of the mean**	**Sample size**
tree shelters	6.4 cm	0.64	278
no tree shelters	2.8 cm	0.59	291

Competition

Competition is an important factor in the success or failure of red oak seedling establishment. Three components making up competition are number of competing tree seedlings and shrubs, height of competing tree seedlings and shrubs, and impact of the overstory (Kolb and Steiner 1989, Myers *et al.* 1989, Kolb *et al.* 1989).

Number of competing seedlings

The average total number of competing seedlings and shrubs by regeneration technique at the end of the establishment year (1991) are presented in Table 7. There was no significant difference in the number of competing tree seedlings and shrubs by regeneration technique for the first growing season (Pr>F = 0.21).

Table 7.—The number of competing seedlings and shrubs/ha for each regeneration technique

Regeneration technique	**No. of competing shrubs & seedlings/ha**	**Standard error of the mean**	**Sample size**
nat. regen. undisturbed	7,100	826	15
not undercut seedlings	6,300	723	15
undercut seedlings	6,900	929	15

The total number of competing seedlings and shrubs is just one factor that is important when looking at the number of competing tree seedlings and shrubs. The number of new competing tree seedlings and shrubs is also important because regeneration techniques may stimulate new competition. The average number of competing tree seedlings and shrubs that were less than 4 mm in ground-line diameter by regeneration technique at the end of the establishment year (1991) are presented in Table 8. This comparison indicates that none of the regeneration techniques stimulated a great increase in the number of new, competing tree seedlings and shrubs (Pr>F = 0.50).

Table 8.—The number of competing seedlings and shrubs/ha that were less than 4 mm in ground-line diameter for each regeneration technique

Regeneration technique	**No. of new competing shrubs & seedlings/ha**	**Standard error of the mean**	**Sample size**
not undercut seedlings	4,244	1,508	15
nat. regen. undisturbed	3,111	1,492	15
undercut seedlings	2,956	768	15

The average numbers of competing seedlings and shrubs at the end of the establishment year (1991) for the unsprayed and sprayed areas were 7,800/ha (s = 3,000/ha) (sample size: n = 48) and 4,500/ha (s = 2,500/ha) (n = 46), respectively. Spraying the area in the fall (1990) before planting in the spring (1991) reduced the competition by 42 percent (3,300 seedlings and shrubs/ha) (Pr>F = 0.0028). The average numbers of competing seedlings and shrubs that were less than 4 mm in ground-line diameter at the end of the establishment year (1991) for the unsprayed and sprayed areas were 1,573/ha (s = 2,647/ha) (n = 48) and 956/ha (s = 1,055/ha) (n = 46), respectively. Spraying before planting did not create conditions for regeneration of competing seedlings and shrubs because the number of seedlings and shrubs that were less than 4 mm in ground-line diameter did not increase significantly (Pr>F = 0.56).

Height of competing seedlings and shrubs

Comparisons were made of average seedling height between the underplanted red oak seedlings and the competition in each treatment area (Table 9). All treatment areas had competing seedlings and shrubs with an average height at the end of the growing season greater than red oak seedlings established during the first year. The treatments seem to have very little effect on the average height of the competing seedlings and shrubs (Pr>F = 0.56).

Table 9.—Comparison of average competing seedling heights with red oak seedling heights for natural regeneration undisturbed (control), for each root class of 1-0 northern red oak seedlings not undercut (SG), and for each root class of 1-0 northern red oak seedlings undercut (UP)

Technique		**Control**	**SG**	**UP**
Competition Avg ht. (cm)		45	41	42
Standard error of the mean		1.2	2.2	1.6
Sample size		792	707	772
1-0 Northern red oak with root class:				
0-4	avg. ht (cm)		22	21
	Standard error of the mean		1.6	2.8
	Sample size		94	90
5-9	avg. ht (cm)		26	22
	Standard error of the mean		1.4	0.9
	Sample size		101	89
10 or more	avg. ht (cm)		39	26
	Standard error of the mean		1.0	1.1
	Sample size		94	101

Overstory impact

To analyze the effect of overstory density on seedlings, linear regression was used to test the effect of average basal area on percentage of survival and average height growth. Seedlings protected by tree shelters were chosen, because they performed the best in survival and height growth. The tests indicated that overstory density had no major effect on percentage of survival ($r^2 = 0.042$) or average height growth ($r^2 = 0.003$).

DISCUSSION

Underplanted Seedling Performance

Based on first year results, the number of lateral roots (greater than 1 mm.) and planting in tree shelters seem to be important factors in establishing underplanted northern red oak seedlings. Planting in tree shelters significantly affected survival and average height growth. Seedlings planted in tree shelters had a 7% better survival rate than seedlings not in tree shelters. Tree sheltered seedlings had an average height growth of 128% more than seedlings not planted in tree shelters. Seedlings with 10 or more first-order lateral roots outperformed seedlings with 5-9 first-order lateral roots by 70%, and seedlings with 0-4 first-order lateral roots, by 369% in average height growth.

The response in survival and height growth of underplanted northern red oak seedlings the first year after planting may actually be related to the treatment that the seedlings received in the nursery. Studies by Schultz and Thompson (1991) have shown that survival and growth of northern red oak seedlings are strongly correlated with the number of permanent first-order lateral roots that the seedlings developed in the nursery. Seedlings planted in tree shelters outperformed seedlings without tree shelters in survival and height growth. This performance is consistent with studies conducted by Tuley (1985), Potter (1991), Teclaw and Isebrands (1991), and Minter *et al.* (1992). Trends in survival and height growth indicate that seedlings with 10 or more first-order lateral roots will outperform seedlings with 5-9 and 0-4 first-order lateral roots. This response is consistent with studies conducted by Schultz and Thompson (1991), who have shown that seedlings with six or more permanent first-order lateral roots generally have the best performance in survival and height growth. This performance is expected because of the size of the root system. The larger the root system the better the seedlings perform. Struve (1990) indicates that the number of first-order, lateral roots are important, because these roots form the basic framework for the new root network. The greater the number of permanent, first-order, lateral roots, the greater is the potential for growth.

Undercut seedlings tended to grow less in height than seedlings that were not undercut, especially seedlings with a larger number of first order lateral roots. This finding is opposite of what would be expected, but may result from the undercut seedlings being 21.6% smaller in initial height than seedlings that were not undercut. The difference in average height growth between the undercut and not undercut seedlings may be due to the difference in photosynthate allocation while the seedlings were in the nursery. Undercutting seedlings in the nursery, probably stimulated them to put photosynthate in excess of respiration into new root production; thereby reducing top growth and the bud component for the next year (i.e., establishment year, 1991). Because oak is a fixed grower (growth is set in the bud), the seedlings that were not undercut would have a greater potential for top growth during the first growing season in the field than seedlings that were undercut. This is consistent with Dickson (1991), where under less than favorable conditions, such as transplant shock, red oak seedlings stopped top growth and allocated photosynthate to root growth and storage.

Competition

Spraying the area with glyphosate herbicide before planting reduced the number of seedlings and shrubs competing with red oak regeneration by 42%, but did not accelerate growth of the underplanted red oak seedlings in the sprayed areas compared with the unsprayed areas. This lack of accelerated growth was not surprising because northern red oak is a fixed grower. Under less than favorable conditions caused by overstory and understory competition, lack of rain fall, and transplant shock, red oak will stop top growth and allocate photosynthate to root growth and storage (Dickson, 1991).

For the red oak seedlings to be a major component in the new stand, they will have to grow faster and be taller than the competition. The only red oak seedlings close in average height to the competition at the end of the establishment year were underplanted red oak seedlings that were not undercut and had 10 or more first-order lateral roots at the time of planting. The underplanted red oak seedlings that were not undercut and had 10 or more first-order lateral roots were 17% smaller than the competition.

The number of competing seedlings and overstory density had little effect on survival or height growth of northern red oak regeneration during the first growing season.

CONCLUSION

It is premature to prescribe a method for regenerating northern red oak based only on the first-growing season. Based on first-growing season results, however, protection by tree shelters and the number of lateral roots greater than 1 mm seem to be important factors in the survival and height growth of underplanted northern red oak seedlings. Trends in survival and height growth indicate that seedlings with 10 or more first-order, lateral roots might be the most successful in underplanting situations, compared with seedlings with fewer first-order, lateral roots. Underplanted seedlings protected by tree shelters performed better in height growth and survival than seedlings not protected by tree shelters. The seedlings in tree shelters are expected to continue this performance in height growth and survival until they have grown out the tops of the shelters. Based on first-year data, underplanting seedlings with large numbers of first-order, lateral roots and using tree shelters may be a viable solution to establishing northern red oak regeneration if such a system is economically feasible.

Data from the study show that a foliar application of glyphosate herbicide reduced the amount of vegetation competing with northern red oak regeneration. Greater survival and better growth is expected to be related to reduced competition. If greater survival and better growth are sustained for a significant time, then spraying the area may be an important part of establishing red oak regeneration.

Data from more than one year will be needed to prescribe suitable methods for regenerating northern red oak. But, data from the first-year of this study and studies conducted by other researchers indicate that the use of tree shelters (Tuley 1985, Potter 1991, Teclaw and Isebrands 1991, Minter *et al.* 1992) and planting northern red oak seedlings with 5 or more first-order, lateral roots, greater than 1 mm (Schultz and Thompson 1991) improve the chances of successfully establishing red oak regeneration.

LITERATURE CITED

Carvell, K. L. 1979. Factors affecting the abundance, vigor, and growth response of understory oak seedlings. Pages 23-26 in Proceedings: Regenerating Oaks in Upland Hardwood Forests. John S. Wright Forestry Conference, Purdue University, Lafayette, IN.

Coder, K. D. 1985. Regeneration ecology of oak in eastern Iowa. Ames, IA: Iowa State University; Dissertation.

Crow, T. R. 1988. Reproductive mode and mechanisms for self-replacement of northern red oak (Quercus rubra) - a review. For. Sci. 34:19-40

Dickson, R. E. 1991. Episodic growth and carbon physiology in northern red oak. Pages 117-124 in Proceedings: The Oak Resources in the Upper Midwest Conference. Winona, MN.

Ehrenfeld, J. G. 1980. Understory response to canopy gaps of various size in a mature oak forest. Bull. Torrey Bot. Club 107:29-41

Fenton, T. E. 1992. Lucas County Interim Report. In preparation. U. S. Department of Agriculture Soil Conservation Service in Cooperation with Iowa Agriculture and Home Economics Exp. Sta. Cooperative Extension Service, Iowa State Univ. Ames, IA.

Gingrich, S. F. 1971. Management of young and intermediate stands of upland hardwoods. USDA For. Serv. Res. Pap. NE-195. Northeast. For. Exper. Stn., Upper Darby, PA.

Holt, H. A. and B. C. Fisher (eds.). 1979. Regenerating oaks in upland hardwood forests. Proc. John S. Wright Memorial Conf. (Purdue Univ.), 132 p.

Johnson, P. S. 1976. Eight-year performance of interplanted hardwoods in southern Wisconsin oak clearcut. USDA For. Serv. Res. Pap. NE-126. North East. For. Exp. Stn. 9 p.

Johnson, P.S. and R. D. Jacobs. 1988. Northern red oak regeneration after preherbicide clearcutting and shelterwood removal cutting. USDA For. Serv. Res. Pap. NC-202. North Cent. For. Exp. Stn., St. Paul, MN. 5 p.

Johnson, P. S., R. D. Jacobs, A. J. Martin, and E. D. Godel. 1989. Regenerating northern red oak: three successful case histories. North J. of Appl. For. 6:174-178

Johnson P. S., S. L. Novinger, and W. G. Mares. 1984. Root, shoot, and leaf area growth potentials of northern red oak planting stock. For. Sci. 30(4): 1017-1026.

Johnson, R. L. 1981. Oak seeding — it can work. South J. of Appl. For. 5: 28-33

Kolb, T. E. and K. C. Steiner. 1989. Competitive ability and growth allocation of planted northern red oak and yellow-poplar seedlings. Pages 62-66 in Proceedings: Seventh Central Hardwood Conference. Southern Illinois Univ., Carbondale, IL.

Kolb, T. E. and K. C. Steiner. 1990. Growth and biomass partitioning of northern red oak and yellow-poplar seedlings: effects of shading and grass root competition. For. Sci. 36(1) 34-44

Kolb, T. E., T. W. Bowersox, L. H. McCormick, and K. C. Steiner. 1989. Effects of shade and herbaceous vegetation on first-year germination and growth of direct-seeded northern red oak, white ash, white pine, and yellow-poplar. Pages 156-161 in Proceedings: Seventh Central Hardwood Conference. Southern Illinois Univ., Carbondale, IL.

Loftis, D. L. 1985 Preharvest herbicide treatment improves regeneration in southern Appalachian hardwoods. South. J. of Appl. For. 9:170-180

Lorimer, C. G. 1989. The oak regeneration problem: new evidence on causes and possible solutions. In Forest Resource Analyses, Number 8, Dept. Forestry, Univ. Wisconsin-Madison. 31 p.

Minter, W. F., R. K. Meyers, and B. C. Fischer. 1992. Effects of tree shelters on northern red oak seedlings planted in harvested forest openings. North J. of Appl. For. 9:58-63

Myers, R. K., B. C. Fischer, and G. M. Wright. 1989. Survival and development of underplanted northern red oak seedlings: 6-year results. Pages 150-155 in Proceedings: Seventh Central Hardwood Conference. Southern Illinois Univ., Carbondale, IL.

NOAA. 1991. National Oceanic Atmospheric Administration. Climatological Data Iowa. Iowa State Univ., Ames, IA. 102(1-12)

Potter, M. J. 1991. Treeshelters. Forestry Commission Handbook 7. London, England. 45 p.

Sander, I. L. 1977. Manager's handbook for oaks in the North Central States. USDA For. Serv. Gen. Tech. Rep. NC-37. North Cent. For. Exp. Stn., St. Paul, MN. 35 p.

Sander, I. L., P. S. Johnson, and R. Rogers. 1984. Evaluating oak advance reproduction in the Missouri Ozarks. USDA For. Serv. Res. Pap. NC-251. 16 p.

SAS Institute Inc. SAS/STAT User's Guide, Release 6.03 Edition. Cary, NC: SAS Institute Inc., 1988. 1,028 p.

Schlesinger, R. C. 1976. Hard maples increasing in an upland hardwood stand. Pages 177-185 in Proceedings: Central Hardwood Forest Conf. I (ed. by J. S. Fralish, G. T. Weaver, and R. C. Schlesinger), Southern Illinois Univ., Carbondale, IL.

Schultz, R. C. and J. R. Thompson. 1991. The quality of oak seedlings needed for successful artificial regeneration in the central states. Pages 180-186 in Proceedings: The Oak Resource in the Upper Midwest Conference. Winona, MN.

Struve, D. K. 1990. Root regeneration in transplanted deciduous nursery stock. HortScience. 25(3): 266-269

Teclaw, R. M. and J. G. Isebrands. 1991. Artificial regeneration of northern red oak in the lake states. Pages 189-195 in Proceedings: The Oak Resources in the Upper Midwest Conference. Winona, MN.

Tuley, G. 1985. The growth of young oak trees in shelters. Forestry 58(2):184-195.

Vegetative Propagation of Mature and Juvenile Northern Red Oak

James J. Zaczek, K. C. Steiner, and C. W. Heuser, Jr.[1]

Abstract: Rooting trials were established to evaluate rooting success of cuttings from mature and juvenile, grafted and ungrafted northern red oak (NRO). Buds from 4 mature NRO ortets and juvenile seedlings were grafted onto juvenile and mature rootstock. Cuttings were collected from the grafts and from juvenile and mature shoots developed *in situ* and subjected to a rooting trial. Of all treatments, cuttings from juvenile material rooted best. However, the rooting of cuttings from mature trees was also relatively successful. Rooting success of cuttings was significantly related to ortet genotype and ontogeny and was not directly influenced by grafting. The number of roots per cutting and post-rooting flushing behavior was significantly related to ortet ontogeny. Juvenile rootstock had little effect on the rooting, number of roots per cutting, flushing behavior, and overwintering success of meristems from mature NRO. Mature rootstock negatively influenced the number of roots per cutting, flushing behavior, and overwintering success of shoots from grafted juvenile buds.

INTRODUCTION

Northern red oak (*Quercus rubra* L.) is a wide-spread and abundant species important in both traditional and urban forestry. It is a genetically diverse species (Houston 1987, Kolb and Steiner 1989, Kriebel et al. 1988, Schlarbaum and Bagley 1981) and therefore offers great potential for tree improvement. Vegetative propagation, especially from mature individuals, is difficult and a severe hinderance to research and to the full utilization of the genetic variation within this species. The objective of this research was to identify techniques for the successful vegetative propagation of ontogenetically mature northern red oak (NRO).

In many woody species, including NRO, juvenile plant materials can be vegetatively propagated more successfully than mature (Burger and Lee 1987, Morgan 1986, Teclaw and Isebrands 1987, Vieitez et al. 1987). Successful rooting of cuttings has been demonstrated for juvenile NRO (Maynard and Bassuk 1987, Teclaw and Isebrands 1987) but success drops off precipitously as early as the second flush from a germinated acorn. The same propagation techniques have not been successful with ontogenetically mature oaks and multiplication of unproven juvenile genotypes has limited applications. Other propagation methods, such as tissue culturing and somatic embryogenesis, are difficult in woody plants and, almost without exception, not possible for explants that are beyond the juvenile phase (Bajaj 1986). Although many factors such as plant nutrition, timing, wounding, etiolation, light status, and hormones affect the rooting of cuttings, ontogenetic maturity may be the most important (Dirr and Heuser 1987).

---

[1] James J. Zaczek, Kim C. Steiner, and Charles W. Heuser, Jr. are, respectively, Faculty Research Assistant and Professor, School of Forest Resources, and Associate Professor, Department of Horticulture, The Pennsylvania State University, University Park, PA. 16802.

In some cases, grafting scions from mature plants to juvenile rootstock has resulted in scion growth that was more juvenile-like in character. Doorenboos (1954) demonstrated increased rooting ability of cuttings from mature *Hedera helix* that had been grafted onto juvenile plants. An increase in rooting was also found by Pliego-Alfaro (1981) who grafted buds from a mature avocado tree onto 1-month-old seedlings. The generated stem explants rooted readily. In oak, Moon et al. (1988) reported that two successive graftings (serial grafting) of mature *Q. acutissima* onto 2-year-old understock increased the rooting to 100%. Pliego-Alfaro (1981) and Moon (1988) concluded that grafting of adult tissue to juvenile rootstock apparently caused a phase reversal or rejuvenation of the mature tissues and restored rooting competence.

Rooting success may be increased by grafting but it may not be due to actual ontogenetic rejuvenation of mature tissues. The phases of ontogenetical aging and subsequent maturity are relatively stable and difficult to reverse (Fortanier and Jonkers 1976). In addition, various characteristics differentiating juvenile from mature may be under independent controls (Borchert 1976).

The morphological characteristic most commonly regarded as signaling phase change from juvenility to maturity is the ability to flower or "ripeness to flower" (Waring and Fryman 1976, Morgan 1986). However, mature plants differ from juvenile plants in many characteristics which may appear either before or after flowering competence is achieved. These include growth behavior, bark characteristics, seasonal leaf retention, leaf shape, rooting behavior and cold resistance (Cordero et al. 1985, Greenwood 1984, Hood and Libby 1980, Kramer and Kozlowski 1979). Thus, even if graft-induced "rejuvenation" enhances rooting success of meristems from mature trees, the propagules may have limited applications if they continue to exhibit other mature characteristics. This paper summarizes a two-year study of the effects of grafting on the rooting success and the maturation state of NRO.

MATERIALS AND METHODS

Shoot cuttings were subjected to rooting trials in 1989, 1990, and 1991. For the 1989 trial, cuttings came from mature NRO trees and juvenile seedlings. In 1990, cuttings for the rooting trial came from mature trees. In 1990 and 1991, buds from the same mature genotypes and from juvenile seedlings were grafted on juvenile and mature rootstock. For the 1991 rooting trial, cuttings were collected from the grafts, the same mature ortets, and from juvenile seedlings of different ages.

Mature and Juvenile Plant Material

Four seed-producing NRO ortets provided sources of mature plant material for grafting and cuttings. In June 1991, the trees were 12, 13, 19, and 22 meters tall and 29, 39, 68, 73 centimeters in dbh for ortets 1, 2, 3, and 4, respectively. Cuttings from shoots developed *in situ* on the mature ortets were designated M1, M2, M3, and M4.

For the 1989 rooting trial, cuttings were collected in bulk (JUV) from juvenile seedlings grown from pre-stratified acorns that were sown in pots in April and May of 1989. For the 1991 rooting trial, pre-stratified acorns were sown in pots during April 1991 in a greenhouse and grown to provide 2nd-flush cuttings (J2) for use in the rooting trial. In May 1991, acorns from the same seedlot were similarly sown in pots in a greenhouse to provide 1st-flush cuttings (J1) for use in the rooting trial. Additionally, cuttings were collected from shoots that arose from along the 1st flush of decapitated 1-year-old seedlings (JD's).

Grafting Treatments

In April of 1990, dormant scion wood was collected from the lower 1/3 of the crown of the mature trees. One hundred dormant buds from each ortet were bud-grafted onto 1-year-old potted NRO rootstock. These 1990 grafts are referred to as 90X's (X = genotypes 1, 2, 3, 4). Spring T-budding (Hartmann and Kester 1983) was used, instead of several other grafting methods for the following reasons. It allows for grafting the smallest transferable unit (a meristem) and therefore makes more economical use of propagating scions. This consideration is of particular importance in the rebudding phase where scion wood is limiting. Perhaps most importantly, spring T-budding provides in-phase development of shoots from grafted and *in situ* buds for the rooting trial. The successful 1990 grafts (47%) were maintained throughout the growing season and overwintered in an unheated greenhouse. In 1991, these grafts were used as a source of dormant buds for grafting and as a source of cuttings for the 1991 rooting trial.

In April 1991, approximately 100 dormant buds representing each mature genotype were collected from the 1990 grafts and re-grafted onto one-year-old potted NRO rootstock. Cuttings from these twice-grafted plants are referred to as 9190X's, (X = genotype number 1, 2, 3, or 4). The rootstock population consisted of 4 open-pollinated families of NRO. Seed for two of the rootstock families was collected from mature ortets #2 and #3 in 1989. Identities of the rootstock families were maintained for use in later analyses. The one-year-old rootstocks had been grown in 6.5 cm square by 23 cm tall pots. In addition, approximately 100 dormant buds collected directly from each of the 4 mature ortets (genotypes 1, 2, 3, 4) and from 1-year-old potted seedlings (J) were grafted onto the same 4 families of one-year-old potted NRO rootstock. Cuttings from these once-grafted plants are referred to as 91X's (X = 1, 2, 3, 4 and J). Buds from the mature trees were also grafted on 2-year-old NRO rootstock of unknown parentage. The 2-year-old rootstock were originally bareroot 1-0 nursery grown seedlings which were potted into 10 cm square by 25 cm tall pots in 1990 and grown for 1 year in the greenhouse prior to grafting. Cuttings taken from these grafts are referred to as 291X's (X = genotypes 1, 2, 3, 4).

In April and May 1991, additional grafts using approximately 100 buds from each of 1-year-old seedlings and mature ortet #2 were made onto the lower 1/3 of the crown of mature ortet #1 at this time. Cuttings for these treatments are referred to as J-M1 and M2-M1, respectively.

In May 1991, grafted rootstocks were decapitated just above the grafts to stimulate the grafted buds to break dormancy. Decapitation at this time provided synchrony of budbreak for both the indoor grafts and outdoor *in situ* ortets. At the same time, the 1990 grafts (90X's) were brought into the heated greenhouse to stimulate budbreak.

Rooting Procedures

For the rooting trials, all cuttings were collected in June, after shoots had reached the LAG phase (Hanson et al. 1986). Cuttings from mature trees (MX's) were collected from the lower 1/3 of the crown. Cuttings were collected daily and kept cool and moist until processing during the same day. All leaves were removed from cuttings, except 3 at the apex. The basal end of each cutting was freshly trimmed and dipped in 1.2% w/w IBA and ethanol for 5 seconds and allowed to dry for 1 minute. While drying, the remaining leaves were trimmed perpendicular to the midvein to about 1/2 of their original size. Cuttings were inserted into pre-dibbled holes in moist media (1 perlite : 1 peat : 1 coarse white sand) in 66 cc Ray Leach Pine Cells and lightly watered prior to placement in the rooting chamber.

In 1989 and 1990, cuttings were randomly placed in a high humidity chamber. Intermittent fog was provided by 4 ultrasonic humidifiers (Sunbeam model 667). Light was provided 18 hours per day by alternating Sylvania VHO cool white and Gro-lux fluorescent bulbs placed 40 cm above the cuttings. In 1991, due to increased numbers of cuttings, a larger mist chamber was constructed using the same fogging system in a greenhouse. In both years, benomyl (Benlate at 2.4 gm/l) was sprayed on the leaves every month during the rooting period.

In 1989 and 1990, cuttings were scored for rooting success about 120 days after sticking. Rooting success was defined as the presence of at least one root at least 5 mm in length. In the 1991 test, cuttings were checked for rooting and number of roots per cutting 80 days after sticking. The number of roots per cutting reflects the number of roots >5 mm in length originating from the stem or callus of a cutting. Cuttings that had not rooted after 80 days were placed back into the high humidity chamber and checked again 40 days later. Data summaries reflect the total cuttings rooted over 120 days.

In 1991, 80 days after sticking, those cuttings that had rooted were potted into 6.5 cm square pots by 23 cm tall pots filled with Pro-Mix BX and set into a shaded acclimation tent. For the next 50 days, daylength was supplemented with 18 hours per day of artificial light from sodium vapor lamps. Humidity was initially maintained at 100% and gradually decreased over 20 days to ambient greenhouse levels, at which time the shade was removed. Late-rooting cuttings were acclimated for 10 days. On 7 November 1991, the number of post-rooting flushes on the rooted cuttings were noted and the rooted cuttings were transferred to an unheated greenhouse for overwintering.

Data Collection and Analyses

In this paper we report on the rooting success (percentage of cuttings with roots), number of roots per rooted cutting, post-rooting flushing, and overwintering survival of the various treatments. Chi-square (Roscoe 1975) and logit analysis (Fienberg 1980) were used to statistically test the categorical data (rooting success, flushing, and overwinter survival) at the P=0.05 level. In logit analysis, models are developed relating response variable and explanatory factors. The data were tested to determine fit to the specified model. P-values greater than the significance level (0.05) indicate that the data fits the model and there are relationships between the response variable and the factor(s). Analysis of variance was used to test for treatment differences in the number of roots per cutting. These data were not normally distributed, treatment standard deviations were proportional to the treatment means, and some of the values were less than 10, therefore the dependent variable (number of roots+1) was log transformed to equalize the variances prior to the analysis of variance (Fowler and Cohen 1990).

RESULTS

Rooting Success - Over Years

The rooting of cuttings from mature trees varied greatly by genotype and over years (Table 1). The rooting of genotypes #2 and #3 was consistently best and poorest, respectively. Rooting results of cuttings from mature trees in 1989 and 1990 were similar but more than doubled in 1991. Rooting of cuttings from juvenile seedlings also increased but not as dramatically. Over all years, for cuttings from mature trees, genotype or year alone were not sufficient to model rooting but a model that included both genotype and the year x genotype interaction effect adequately described the data (P=0.246).

Table 1.—Percentage rooting for cuttings from 4 mature trees and juvenile seedlings over years

Cutting type	**1989 % Rooting**	**(n)**	**1990 % Rooting**	**(n)**	**1991 % Rooting**	**(n)**
M1	26.5	(49)	20.8	(72)	56.0	(50)
M2			51.5	(66)	86.0	(50)
M3	0.0	(50)	2.9	(69)	20.0	(50)
M4	11.8	(51)	20.9	(67)	74.0	(50)
JUV	80.0	(100)			88.9	(99)

note: Cutting type JUV represents first- and second-flush cuttings from two- and three-month old juvenile seedlings.

Rooting - 1991 Experiment

In 1991, rooting averaged 72.2% over all treatments but there were large differences among the treatments ranging from 96% for J1 to 20% for M3 cuttings (Table 2). Significant genotypic and ontogenetic effects were present but grafting was not significantly related to rooting.

Genotypic Effects

Rooting was dependent on genotype for mature ungrafted cuttings in 1991 (chi-square, $P<0.001$). For grafted cuttings of known rootstock family, logit analysis revealed that there was no significant rootstock family effect on rooting ($P=0.003$). However, there was a significant relationship between scion genotype and rooting ($P=0.491$).

Grafting Effects

Cuttings from grafts of the mature genotypes rooted more often than their ungrafted counterparts (69% vs 59%). However, when considering genotypes, logit analysis revealed that rooting success was not significantly related to the main effects of grafting or genotype ($P<0.05$). Averaged over genotypes, percent rooting was 56, 59, 70, and 79 for 91X's, mature, 9190X's, and 90X's, respectively. Grafting did decrease the differences between genotypes but not significantly so. Only for #3, the ortet with the poorest rooting performance, did every grafting treatment increase rooting compared to ungrafted controls (from 20 to 58%). Grafting treatments variably affected the other genotypes.

Ontogenetic Effects

Chi-square analysis revealed a significant relationship between rooting success and cutting maturity when comparing all mature cuttings as a group versus all juvenile cuttings ($P<0.001$). Rooting of two-month-old J1 cuttings (96%) was considerably greater than mature cuttings (59%). Interestingly, rooting of only slightly older 3-month-old seedlings (J2) dropped significantly to 82% (chi-square, $P=0.05$) and fell behind one of the 4 mature genotypes. Therefore, chronological age of the plant was not the determining factor of rooting success. This was further evidenced by the 94% rooting success of the 1-year-old JD cuttings.

Table 2.—1991 percent rooting, roots/cutting, and flushing by treatment

Cutting type	Number of cuttings	Rooting (%)	No. roots per cutting	Overwinter surv. (%)
M1	50	56.0	2.0	40.7
M2	50	86.0	4.1	79.4
M3	50	20.0	1.4	20.0
M4	50	74.0	5.8	47.2
J1	50	96.0	14.3	95.8
J2	49	81.6	14.9	80.0
JD	51	94.1	23.4	93.6
901	28	71.4	3.8	60.0
902	76	89.5	6.8	70.3
903	35	71.4	3.2	80.0
904	38	81.6	6.8	77.4
911	39	51.3	3.0	45.0
912	41	70.7	4.9	51.7
913	15	46.7	1.6	28.6
914	37	54.1	4.6	57.9
91J	42	90.5	13.5	70.3
91901	27	81.5	2.8	50.0
91902	44	72.7	4.5	65.6
91903	30	43.3	7.3	54.5
91904	30	83.3	3.6	52.2
2911	28	67.9	2.7	31.6
2912	29	79.3	4.7	54.5
2913	14	71.4	2.7	20.0
2914	35	65.7	3.8	39.1
J-M1	15	93.3	3.0	50.0
M2-M1	11	81.8	5.7	44.4

MX's = mature trees, genotypes 1,2,3,4
J1, J2 = one- and two-flush seedlings, approximately 2 and 3 months old, respectively
JD = 1st flush of one-year-old formerly multiflush but decapitated (clipped off) seedlings
90X's = 1990 grafts, one-year-old stock, X=genotypes 1,2,3,4
91X's = 1991 grafts, one-year-old stock, X=genotypes 1,2,3,4 and J (juvenile)
9190X's = twice grafted on one-year-old stock (1991 and 1990)
291X's = 1991 grafts on two-year-old stock, genotypes 1,2,3,4
J-M1 = juvenile buds grafted on mature tree #1
M2-M1 = mature genotype #2 grafted on mature tree #1

To test if buds are influenced by the environment (either juvenile or mature rootstock) in which they are formed during the growing season prior to shoot formation, a logit model was constructed pooling 90X's and 9190X's vs 91X's and 291X's (X = mature genotypes 1, 2, 3, and 4). Considering only the 4 mature genotypes, shoot cuttings from the 90X's and 9190X's grafts came from buds formed on juvenile rootstock and shoot cuttings from the 91X's and 291X's grafts arose from buds that were formed on the mature trees. Logit analysis revealed that rooting success was not significantly related to bud formation environment prior to grafting (P=0.002).

Number of Roots Per Rooted Cutting

There were significant differences among the treatments for the number of roots per cutting (P<0.0001). Rooted cuttings from juvenile seedlings had significantly more roots per cutting than those from mature trees (Table 2). Grafting treatments using juvenile rootstock did not significantly influence the number of roots per cutting. Based on the number of roots per rooted cutting, there is no evidence of grafting-induced rejuvenation.

Cuttings from juvenile buds that were grafted onto a mature tree (J-M1) had significantly fewer roots (3.0) compared to cuttings from juvenile seedlings (23.3, 14.9, 14.3 for JD, J2 and J1, respectively) and to cuttings from juvenile buds grafted onto juvenile rootstock (13.5 for 91J). There apparently was an influence of the mature rootstock on the number of roots per rooted cutting but not on rooting success, suggesting that these measures of juvenility were independently controlled.

Flushing Behavior, Post-Rooting

Shoot flushing of NRO seedlings can consist of a series of recurrent and determinate flushes (Borchert 1975). In contrast, mature trees usually produce only one flush of vegetative growth per growing season. Flushing behavior was noted as an indicator of maturity.

After the cuttings had rooted and before overwintering, some flushed once or twice. Differences in flushing behavior were apparent among the treatments (Table 3). Flushing data were similar and combined for treatments 91X and 291X due to low numbers of genotype #3. Treatments J1 and JD flushed considerably more (83.3% and 85.4%, respectively) than other treatments and a reduction in flushing behavior was apparent as early as the second flush of a seedling (J2=50%). Rooted cuttings from buds from mature trees, whether grafted or not, flushed considerably less.

Flushing averages (%) were 5.7, 15.5, 16.1, and 20.3 for rooted cuttings from ungrafted mature, 90X's, 91X+291X's, and 9190X's treatments. Considering genotype and whether grafted or not, logit analysis revealed that the flushing behavior data were not described by models using either grafting or genotype main effects. However, a model including the grafting main effect with the grafting x genotype interaction fit the data (P=0.906). The interaction apparently arose from the increase of flushing of genotypes #3 and #4 when grafted giving some evidence for the occurrence of ontogenetic rejuvenation. Interestingly, the mature rootstock negatively influenced flushing when comparing rooted cuttings from juvenile buds grafted onto the mature tree (14.3%) and those grafted onto juvenile rootstock (47.4%).

Table 3.—Percent of rooted cuttings that flushed at least once before overwintering

	BUD TYPE						
Grafting treatment	**M1**	**M2**	**M3**	**M4**	**J1**	**J2**	**JD**
not grafted (%)	10.7	9.3	0.0	2.8	83.3	50.0	85.4
(n)	(28)	(43)	(10)	(37)	(42)	(40)	(48)
90X's (%)	5.0	11.9	31.0	12.9			
(n)	(20)	(67)	(25)	(31)			
91X+291X's (%)	5.1	5.8	35.3	18.2		47.4*	
(n)	(39)	(52)	(17)	(44)		(38)	
9190X's (%)	9.1	9.4	38.5	24.0			
(n)	(22)	(32)	(13)	(25)			
grafted onto M1 (%)		0.0				14.3*	
(n)		(9)				(14)	

* = buds used for grafting were from 1-year-old multi-flush seedlings

Overwinter Survival

By June 1992, 63% of the 1991 rooted cuttings were alive. Differences in overwinter survival closely mirrored rooting success (Table 2). For the most part, those treatments that had high rooting success (J's), overwintered well (90% survival) and those that had poor rooting success (M3), had poor overwinter survival (20%).

Overwinter survival was related to rooting date. For cuttings that had rooted by 80 days, 70% survived, compared to those that rooted after 80 days, only 25% survived. Of all juvenile treatments that had rooted, 97% had done so within 80 days. Only 62% of all treatments using ortet #3 had rooted by that time. Perhaps the cuttings that were early rooters were able to store more photosynthate and harden-off more completely than the late rooters. Post-rooting flushing behavior and the number of roots per cutting did not appear to directly influence overwinter survival as within-treatment averages for dead and surviving rooted cuttings were similar. Although the actual cause(s) of overwinter mortality was not certain, the roots of many of the dead rooted cuttings were infected with *Phytophthora*.

DISCUSSION

In 1989 and 1990, rooting success for cuttings of mature NRO was generally low and consistent with the conventional wisdom that oaks are difficult to vegetatively propagate (Clark 1962, Flemer 1962, Hartman and Kester 1983, Morgan 1986). However, in 1991, rooting success of cuttings from mature NRO increased dramatically and more than doubled to 59%. At this time, we have no definitive explanation for this increase but are actively pursuing several possibilities related to environmental conditions present in the different rooting chamber used in the 1991 experiment. The high level of rooting success in 1991 does not appear to be a spurious result as an additional rooting experiment performed in the same chamber in 1992 achieved similar high rooting success. Even with relatively high rooting success, large differences in responses were apparent among treatments. For cuttings from mature trees, significant genotypic effects were found for rooting and overwintering success. Even after grafting, which decreased the differences in rooting, significant genotypic effects persisted. Other studies have demonstrated genotypic effects when rooting cuttings of other species (Burger and Lee 1987, Larsen 1986, Morgan 1986).

Ontogenetic effects were apparent for all characteristics measured. Other studies have shown significant juvenile to mature change in vegetative propagation success (Morgan 1986, Pleigo-Alfaro 1981, Vieitez et al. 1987) and this was often related to chronological age of the ortet. We experienced a similar relationship but with some qualifications. Rooting and overwintering survival decreased significantly in a relatively short time when comparing 2-month-old (J1) and 3-month-old (J2) seedlings. This was also found by Isebrands and Crow (1985) and Teclaw and Isebrands (1987) when comparing 1- and 2-flush NRO. However, chronological age was not a good predictor of success as older (1-year-old) JD seedlings did not further decline but rooted, flushed, and survived at levels similar to J1 seedlings. Ontogenetic effects are somewhat obscured by the ease of rooting and high overwintering percentages of cuttings from the much older and much larger M2 ortet. Flushing behavior and the number of roots per rooted cutting were strongly related to donor plant ontogeny regardless of whether or not it had been grafted onto juvenile rootstock.

Juvenile rootstock had no significant main effect on rooting success, the number of roots per rooted cutting, and overwinter survival. For these responses, shoot system differences (genotypic and ontogenetic) were maintained. This agrees, in part, with a study by Anderson et al. (1991) using loblolly pine (*Pinus taeda*). He concluded that expression of morphological characteristics in shoot systems of mature tissue-cultured plantlets and juvenile seedlings grafted onto seedling and plantlet root systems is controlled almost entirely by the shoot system and is not directly related to the root systems. However, in our comparison of the reciprocal grafts (buds from juvenile seedlings grafted onto mature), we have found evidence to the contrary.

Cuttings from juvenile buds grafted onto mature rootstock rooted in percentages similar to those grafted onto juvenile rootstock but had fewer roots per cutting, decreased flushing, and lower overwintering success. Mature rootstocks were apparently inhibitory for three of the measured characteristics, but not all four. There were also differences between J1 and J2 cuttings in rooting, flushing, and overwintering success but not for the numbers of roots per rooted cutting. This suggests that the responses are under relatively independent control. Borchert (1976) also suggests relatively independent control mechanisms for various juvenile characteristics.

In this study, the relatively small influence of juvenile rootstock on mature meristems does not appear to be due to ontogenetic rejuvenation but possibly physiological invigoration of the resulting shoots. For the most part, meristems appear to have predetermined rooting responses regardless of grafting. In mature oaks, dormant buds develop during the growing season prior to dormancy into either vegetative or mixed buds (containing both leaf and flower primordia) (Kozlowski 1971, Merkle et al. 1980). Assuming the differences between juvenile and mature shoots for rooting success are pre-determined in buds, then expansion of pre-formed buds originally set on a mature tree, whether it occurs *in situ* or grafted onto juvenile rootstock, should result in shoots that perform similarly. It follows that if ontogenetic rejuvenation of a meristem were to occur as influenced by juvenile rootstock, it must happen during the time of bud formation when the primordia for the next flush are formed. In our study, the corresponding treatments would be the 90X's and the 9190X's for which cuttings came from buds that formed on juvenile rootstock. The different environment provided by the juvenile rootstock during bud formation apparently did not change the mature character of the meristems and, for the most part, the cuttings responded similarly to their grafted (91X's and 291X's) or ungrafted counterparts.

Physiological invigoration of the grafted shoots by the rootstock is also supported when comparing 291X's vs 91X's. Cuttings from all of the 4 mature genotypes that had been grafted onto the older and larger rootstock (291X's) rooted more often than cuttings from younger and smaller rootstock. The more vigorous rootstock produced cuttings that were more successful rooters.

The presence of significant interactive effects suggest that if ontogenetic rejuvenation is possible, it may be genotypically dependent. It is also possible that it may take additional grafting phases for more definitive indications of rejuvenation to be manifested. In avocado, it was found that three re-grafts of mature scion shoots did not increase rooting but there was evidence that additional regrafts might improve rooting (Pliego-Alfaro and Murashige 1987). When tissue culturing *Vitis vinifera* L., Mullins et al. (1979) found that it took from 3 to 7 subcultures for shoot tips to show juvenile characteristics.

CONCLUSIONS

Juvenile rootstock had little effect on the rooting of cuttings developed from grafted buds of mature NRO. There was little evidence of ontogenetic rejuvenation of the previously grafted propagules and they appeared to maintain mature characteristics. In spite of this, rooting of mature NRO proved to be relatively successful achieving levels potentially feasible for large scale clonal production. Though one or two series of grafts onto juvenile rootstock did not significantly increase rooting or unequivocally invoke rejuvenation, grafting can be used to multiply shoots of mature genotypes while apparently maintaining their ontogenetic state. Rooted cuttings of select NRO exhibiting mature characteristics could prove to be valuable for use in physiological studies or for tree improvement work in order to establish slow-growing and early-flowering seed orchards free from graft incompatibility problems that can occur with oak. If additional re-grafting or post-rooting treatments provides evidence of ontogenetic phase reversion, rejuvenated rooted cuttings could be used as fast-growing planting stock for reforestation.

ACKNOWLEDGEMENTS

The authors would like to thank Dr. Walter M. Tzilkowski for his help with the statistical analyses in the study.

LITERATURE CITED

Anderson, A.B., L.J. Frampton, Jr., S.E. McKeand, and J.F. Hodges. 1992. Tissue-culture shoot and root system effects on field performance of loblolly pine. Can. J. For. Res. 22:56-61.

Bajaj, Y.P.S. 1986. Biotechnology in Agriculture and Forestry - Trees 1. Springer-Verlag, New York.

Borchert, R. 1975. Endogenous shoot growth rhythms and indeterminite shoot growth in oak. Physiol. Plant. 35:152-157.

Borchert, R. 1976. The concept of juvenility in woody plants. Acta Horticulturae. 56:21-33.

Burger, D.W. and C.I. Lee. 1987. Genetic variability in the propagation of *Eucalyptus sideroxylon* by stem cuttings. J. Environ. Hort. 5(1):31-32.

Clark, R.A. 1962. Rooting of epicrmic branches of red oak and sugar maple. Thesis. The Pennsylvania State University. 47pp.

Cordero, R.E., J.R. Murray, and W.P. Hackett. 1985. Plastochron indicies for juvenile and mature forms of *Hedera helix* L. (Araliaceae). Am. J. Bot. 72:324-327.

Dirr, M.A,. and C.W. Heuser, Jr. 1987. The Reference Manual of Woody Plant Propagation: From Seed to Tissue Culture. Varsity Press, Athens, GA.

Doorenbos, J. 1954. Rejuvenation of *Hedera helix* in graft combinations. Proc. Kon. Ned. Akad. Wet., Series C. 57:99-102.

Fienberg, S.E. 1980. The Analysis of Cross-Classified Categorical Data. MIT Press, Cambridge, Mass.

Flemer, W. III. 1962. The vegetative propagation of oaks. Int. Plant Prop. Soc. Comb. Proc. 12:168-173.

Fortanier, E.J., and H. Jonkers. 1976. Juvenility and maturity of plants as influenced by their ontogenetical and physiological ageing. Acta Horticulturae 56:37-45.

Fowler, J., and L. Cohen. 1990. Practical Statistics for Field Biology. Open University Press, Bristol Penn. 227 p.

Greenwood, M.S. 1984. Phase change in loblolly pine: Shoot development as a function of age. Physiol. Plant. 61:518-522.

Hanson, P.J., R.E. Dickson, J.G. Isebrands, T.R. Crow, and R.K. Dixon. 1986. A morphological index of *Quercus* seedlings ontogeny for use in studies of physiology and growth. Tree Phys. 2:273-281.

Hartmann, H.T., and D.E. Kester. 1983. Plant Propagation. 4th ed. Prentice Hall, Englewood Cliffs, NJ.

Hood, J.V., and W.J. Libby, Jr. 1980. A clonal study of intraspecific variation in radiata pine. I. Cold and animal damage. Austral. For. Res. 10:9-20.

Houston, D.B. 1987. Variation in southern seed sources of northern red oak. Proc. North Central Tree Improv. Conf. 5:132-140.

Isebrands, J.G., and T.R. Crow. 1985. Techniques for rooting juvenile softwood cuttings of northern red oak. Proc. 5th Central Hwds. For. Conf. Univ of Ill.

Kozlowski, T.T. 1971. Growth and Development of Trees. Vol. 1. Academic Press, New York, 443 p.

Kramer, P.J., and T.T. Kozlowski, 1979. Physiology of Woody Plants. Academic Press, New York, N.Y.

Kriebel, H.B., C. Merritt, and T. Stadt. 1988. Genetics of growth rate in *Quercus rubra*: Provenance and family effects by the early third decade in the North Central U.S.A. Silv. Gen. 37:193-198.

Kolb, T.E. and K.C. Steiner. 1989. Genetic variation among and within single-tree progenies of northern red oak. For. Sci. 35:251-256.

Larsen, O.N. 1986. Clonal propagation of *Fagus sylvatica* L. by cuttings. The Int. Plant Prop. Soc., Comb. Proc. 35:438-442.

Maynard, B.K., and N.L. Bassuk. 1987. Stockplant etiolation and blanching of woody plants prior to cutting propagation. J. Amer. Soc. Hort. Sci. 112(2):273-276.

Merkle, S.A., P.P. Feret, J.G. Croxdale, and T.L. Sharik. 1980. Development of floral primordia in white oak. For. Sci. 26:238-250.

Moon, K.M., M.H. Park, K.Y. Lee, and H.P. Park. 1988. Rooted cuttings using juvenile semihardwood of some useful oaks and rooted cuttings of grafted seedlings of *Quercus acutissima* plus tree. Res. Rep. Inst. For. Gen. Korea 24:42-46.

Morgan, D.L. 1986. Propagation of *Quercus virginiana* cuttings. The Int. Plant Prop. Soc., Comb. Proc. 35:716-719

Mullins, M.G., P. Nair, and P. Simpet. 1979. Rejuvenation *in vitro*: induction of juvenile characters in an adult clone of *Vitis vinifera* L. Ann. Bot. 44:623-627.

Pliego-Alfaro, F. 1981. A morphogenic study of the Avocado *in vitro*. Dissertation, Univ. of California at Riverside. 153 p.

Pliego-Alfaro, F. and T. Murashige. 1987. Possible rejuvenation of adult avocado by graftage onto juvenile rootstocks *in vitro*. Hort Science 22(6):1321-1324.

Roscoe, J.T. 1975. Fundamental Research Statistics for the Behavioral Sciences. 2nd Ed. Holt Rinehart and Winston. New York, N. Y.

Schlarbaum, S.E., and W.T. Bagley. 1981. Intraspecific variation of *Quercus rubra* L., northern red oak. Silv. Gen. 30:50-56.

Teclaw, R.M. , and J.G. Isebrands. 1987. Stage of shoot development and concentration of applied hormone affect rooting of northern red oak softwood cuttings. Proc. Southern For. Tree Imp. Cooperative 19:101-108.

Vieitez, J., D.G.I. Kingston, A. Ballester, and E. Vieitez. 1987. Identification of two compounds correlated with the lack of rooting capacity in chestnut cuttings. Tree Physiology (3):247-255.

Waring, P.F., and V.M. Frydman. 1976. General aspects of phase change, with special reference to *Hedera helix* L. Acta Horticulturae 56:57-71.

Survival and Growth of Planted Northern Red Oak in Northern West Virginia[1]

Charles A. McNeel, David M. Hix, and Edwin C. Townsend[2]

Abstract: The survival and growth of northern red oak (*Quercus rubra* L.) seedlings planted beneath a shelterwood in northern West Virginia were evaluated one year after planting. The use of 1.5 m (5 ft) tall TUBEX tree shelters on planted seedlings was also examined. The study was conducted on both excellent and good sites (site indices of 27 m (89 ft) and 22 m (74 ft) for northern red oak, respectively). The overstories on both sites were dominated by yellow-poplar (*Liriodendron tulipifera* L.), white oak (*Quercus alba* L.), and northern red oak. A replicated four-level split-plot experimental design was used. Treatments consisted of: site quality, shelterwood cutting, understory herbicide treatment, and tree shelters. Overstories and understories were manipulated in late winter, and 2-0 northern red oak nursery stock was planted and the tree shelters were installed the following spring. The tree shelters significantly increased seedling height growth but not survival. After one growing season, the survival of planted seedlings was 88%. Sheltered trees grew significantly more in height (21 cm) and were more vigorous than the unsheltered seedlings (11 cm). These initial results suggest that when using the shelterwood method, tree shelters will increase the growth of planted northern red oak seedlings.

INTRODUCTION

Northern red oak (*Quercus rubra* L.) is an important species in the Appalachian hardwood forest. However, it often fails to regenerate even where it predominates in the overstory.

The shelterwood method has been used successfully for about 80 years in many forest regions (Hannah 1988). Hill and Dickman (1988) found that shelterwood cutting can be used to regenerate northern red oak. However, they pointed out the difficulty of keeping oak reproduction competitive in young stands. Loftis (1983 and 1990) similarly advocated using the shelterwood method and controlling undesirable understory stems for regenerating northern red oak. Beck (1988) also reported that understory treatment combined with shelterwood cutting was successful in regenerating upland hardwoods. Graney (1988) likewise indicated that the shelterwood method coupled with understory treatment can encourage the development of desirable reproduction. He found that there was more oak reproduction where shelterwood cutting with understory treatment was used than where understory treatment was not used.

Planting has been used to supplement natural oak regeneration in areas where it is scarce. Tworkoski and others (1986) feel that underplanting is a viable tool if it is done before harvesting.

---

[1] Published with the approval of the Director of the West Virginia Agricultural and Forestry Experiment Station as Scientific Article 2393. This research was supported with funds appropriated under the McIntire-Stennis Act.

[2] Former Research Assistant, Division of Forestry, West Virginia University, Morgantown; Assistant Professor, School of Natural Resources, The Ohio State University, Columbus; and Associate Professor, Statistics, West Virginia University, Morgantown.

An earlier paper by Tworkoski and others (1982) concluded that a combination of shelterwood cutting and underplanting can regenerate northern red oak and white oak. Pubanz and others (1989) found that planted oak seedlings had better survival, growth, and vigor after the overstory was reduced and the understory was removed.

Lorimer (1989) suggested using the shelterwood method combined with intensive understory management for regenerating oaks naturally. However, on good sites he further pointed out that successful oak regeneration might be increased by planting. Johnson (1984) found that acceptable success rates could be obtained in stands where the overstory was thinned and the understory was removed. He defined a success probability as the "probability of a tree attaining some minimum acceptable rate of growth," which he believed was a better measure of planting success than the mean heights of survivors. Johnson and others (1986) also developed a prescription for planting northern red oak. In contrast, Wright and others (1984) found that planted northern red oak survival was acceptable but that the planted trees were unable to remain competitive under a thinned upland hardwood stand in Indiana.

Tuley (1985) demonstrated that tree shelters could increase the growth of oak seedlings as much as 5.2 times over that of unsheltered trees after three years. Similarly, Potter (1988) showed that early height growth could be increased 7- or 8-fold. Potter believed the main reason for this increased growth was the reduction of air movement inside the shelter. The humidity inside the tube was increased, and the possibility of moisture stress was decreased. Since tree taper is also decreased due to the reduced air movement, the saplings had a more columnar form. Minter and others (1992) found that carbon dioxide levels are also higher in shelters, which in turn increases seeding growth rate. Tree shelters also protect trees against many types of animal damage including deer browsing.

The objective of this study is to examine the effects of site quality, shelterwood cutting, understory herbicide treatment, and tree shelters on the survival and growth of planted northern red oak seedlings.

STUDY AREA AND METHODS

This study was conducted on the West Virginia University Forest in northern West Virginia near Morgantown. The study was established in May and June of 1990 and designed as a four-level split-plot experiment. The levels consisted of: site quality, shelterwood cutting, understory herbicide treatment, and planting 2-0 northern red oak nursery stock with and without tree shelters. The entire experimental area was about 5 ha (12.5 ac) in size, with the pairs of 0.4 ha-plots separated by buffer strips.

Stands representing two levels of site quality were selected for study: (1) northwest aspects with an average site index for northern red oak (at 50 years) of 22 m (74 ft), and (2) northeast aspects with an average site index of 27 m (89 ft). There were three pairs of plots on the excellent sites and two pairs on the good sites. The overstories on both sites were yellow-poplar (*Liriodendron tulipifera* L.), white oak, and northern red oak (SAF forest cover type 59). Soils were mapped as Dekalb stony sandy loam with slopes ranging from 20 to 40 percent (Baur 1959).

Shelterwood cutting was randomly applied to one plot in each pair during the spring of 1991. The overstory was reduced to 85% crown cover based on spherical densiometer measurements.

The understory herbicide treatment was randomly applied to half of each plot (a sub-plot) after cutting. This treatment consisted of cutting all non-oak stems less than 4.1 cm dbh (diameter at breast height) and applying a herbicide to the cut stems to control sprouting.

In March of 1991, 2-0 northern red oak nursery stock was planted. Seedlings were obtained from the state nursery at Point Pleasant near Parkersburg, WV. Half of the total of forty 0.04 ha sub-sub-plots were planted at a 3- by 3-m spacing. A total of 500 seedlings were planted among the various treatment combinations on the two sites. The seedlings were pruned 20 cm above and below the root collar to increase their root to shoot ratios. About half of the planted trees were protected by tree shelters. The tree shelters were TUBEX brand and 1.5 m (5 ft) tall. The shelters were pushed down into the ground around the seedlings and fastened to treated wood stakes.

Planted seedlings were measured at the end of the first field growing season. Measurements included: total height, length of last internode, number of leaves (as an indicator of vigor), and a measure of form class. Form class "1" represented flat-topped reproduction, class "3" reproduction had a strong central leader, and class "2" was intermediate in form. Because all stems were top-pruned, analyses were based on the length of the last internode instead of total height. Analysis of variance was based on the split-plot design. However, initial seedling diameter was used as a covariate because plots differed significantly in initial mean diameter. An alpha level of 0.05 was used for all statistical tests for significant differences.

RESULTS AND DISCUSSION

First-growing season survival of planted northern red oak seedlings was not affected by any treatment (including tree shelters) or by site quality. Survival rates for the individual sub-sub-plots in this experiment were all very high and averaged 88 %.

Northern red oak seedlings without tree shelters grew significantly more on good sites than on excellent sites (Figure 1). This may be the result of greater deer browsing on the better sites where deer densities probably were higher. Height growth of sheltered seedlings did not differ by site quality.

Because there were no significant effects due to overstory or understory treatments on both sites, the height growth data were pooled for further analysis. For all sites combined, tree shelters had a positive effect on the growth of planted northern red oak seedlings (Table 1). Sheltered seedlings grew significantly more than unsheltered seedlings (21 versus 11 cm).

Tree shelters also significantly affected the average numbers of leaves on planted northern red oak seedlings (Table 1). Sheltered seedlings produced more leaves than unsheltered seedlings (9.2 versus 6.8). Therefore, sheltered seedlings tended to be more vigorous after the first growing season than unsheltered trees.

Deer also may have affected the form of seedlings on the different sites. Although more seedlings on the good sites had a strong central leader than on the excellent sites, this difference may have been the result of deer browsing.

Seedling form was affected by the tree shelters (Figure 2). Seedlings with tree shelters tended to have stronger central leaders. On the other hand, those without tree shelters were more intermediate in their form.

CONCLUSIONS

Artificial regeneration of northern red oak may be a promising tool in the central Appalachians. Planting northern red oak is a way of supplementing inadequate natural reproduction. During the first field growing season, the seedlings in this study grew well and survival rates were high.

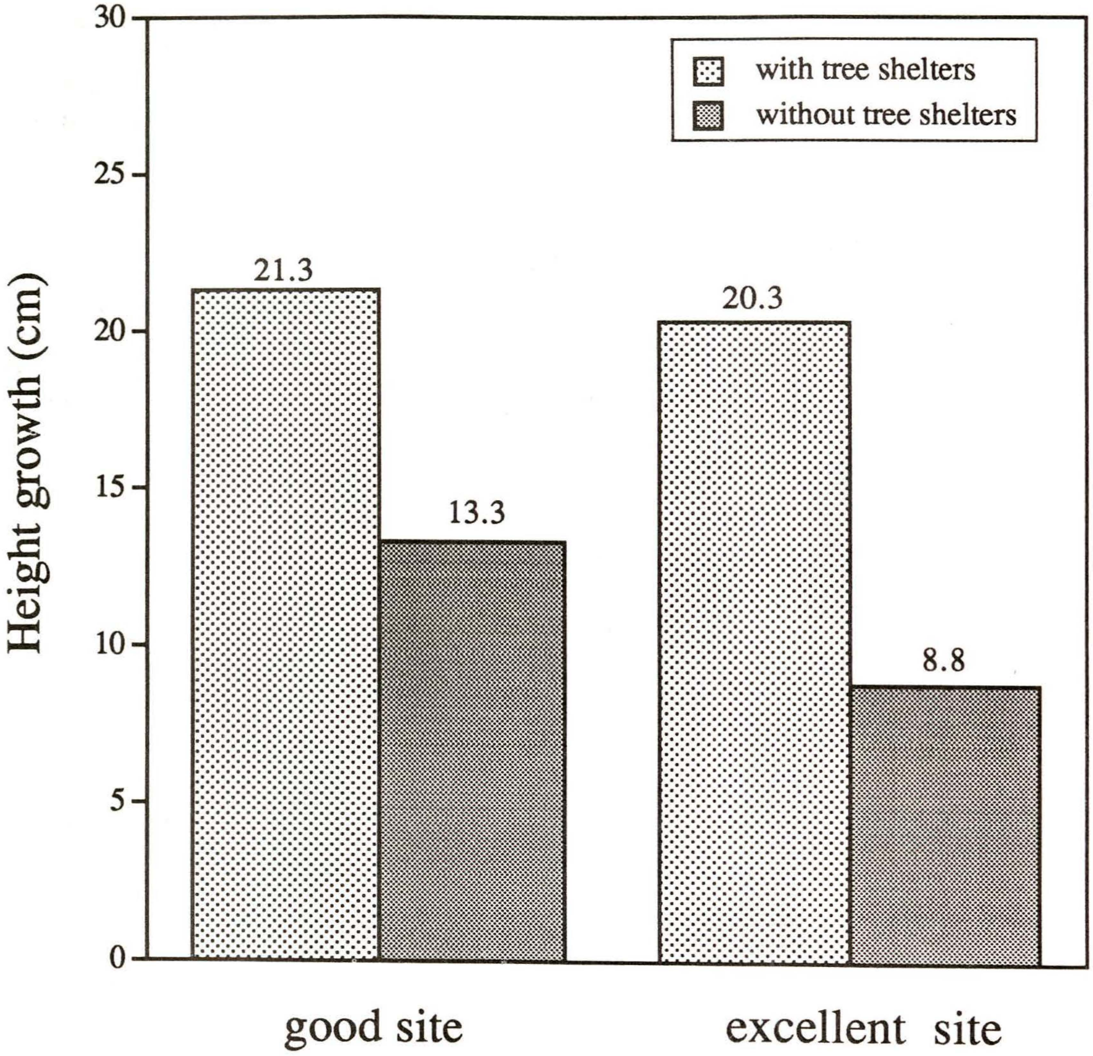


Figure 1.—Planted northern red oak seedlings without tree shelters grew significantly more ($p < 0.05$) on good sites than on excellent sites. There was no significant difference ($p > 0.05$) in growth rate between sites for seedlings with shelters.

Table 1.—Tree shelters significantly increased ($p < 0.05$) the height growth and average number of leaves of planted northern red oak seedlings

	With tree shelters	**Without tree shelters**
Height growth (cm)	20.8	11.1
Average number of leaves	9.2	6.8

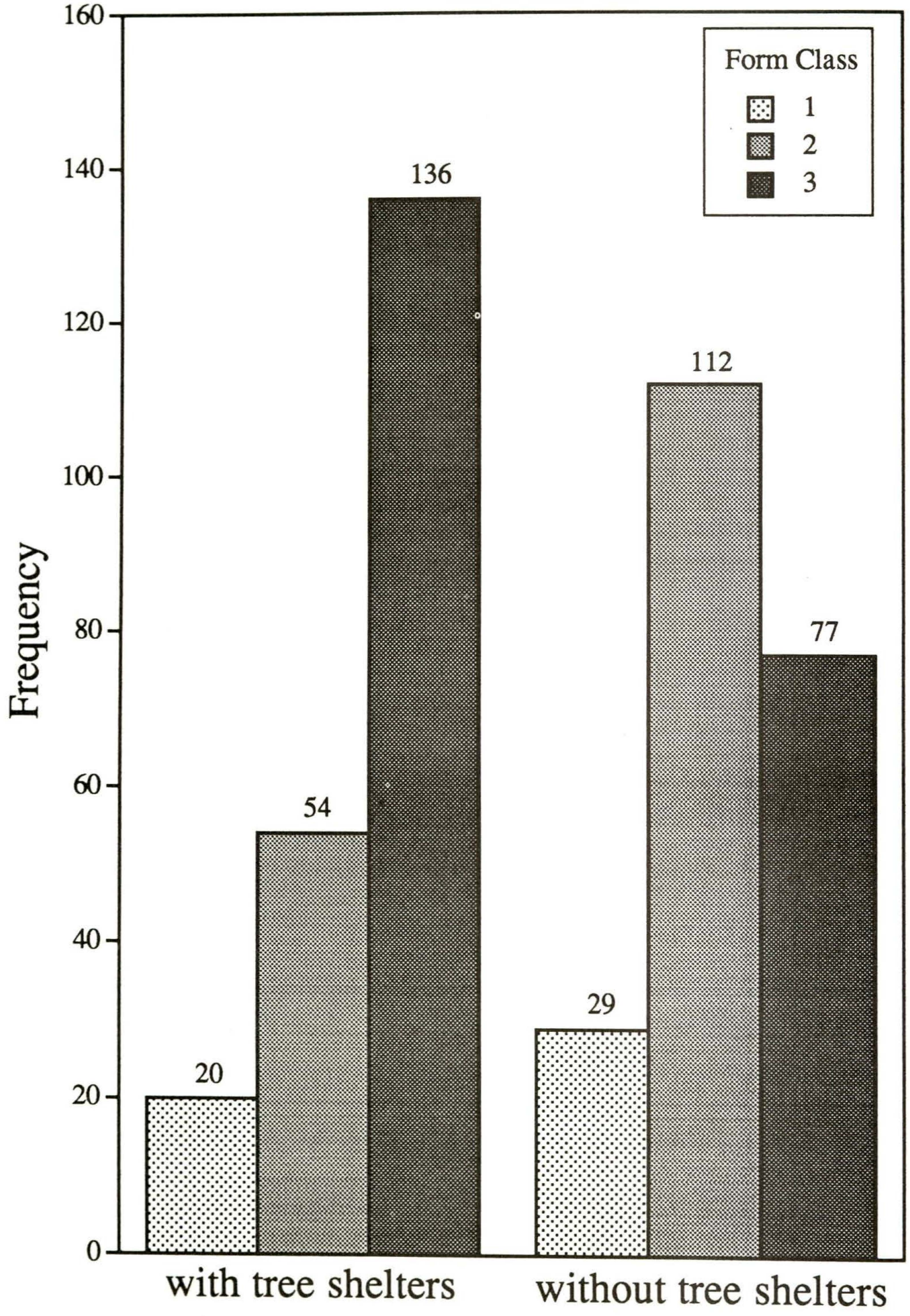


Figure 2.—Frequency of occurrence of the three form classes for planted northern red oak seedlings with and without tree shelters.

However, seedlings planted under a shelterwood did not grow any faster than those planted in uncut stands. Understory herbicide treatment also did not have any significant effects on growth. However, these trends may change.

Tree shelters, nevertheless, had a positive effect on the growth and vigor of northern red oak seedlings during the first growing season. It appears that tree shelters may continue to effect increases in the growth rate of oak seedlings in this area, as they have in other regions. This experiment has shown that tree shelters can promote the early growth of planted northern red oak seedlings. However, the high cost of the shelters may limit their use in extensive forest management applications. Cost analysis studies could ascertain if large-scale planting of northern red oak and using tree shelters on them is economically feasible.

LITERATURE CITED

Baur, A.J. 1959. Soil survey - Preston County, West Virginia. USDA Soil Conservation Service. 50 pp.

Beck, D.E. 1988. Clearcutting and other regeneration options for upland hardwoods. pp. 44-54 in Proc. Sixteenth Annual Symp. of the Hardwood Research Council. Cashiers, NC.

Graney, D.L. 1988. Growth of oak, ash, and cherry reproduction following overstory thinning and understory control in upland hardwood stands of northern Arkansas. pp. 245-252 in Proc. Fifth Biennial Southern Silvicultural Research Conf. Miller, J. H. (ed.) Memphis, TN. Gen. Tech. Rep. SO-74.

Hannah, P.R. 1988. The shelterwood method in northeastern forest types: A literature review. North. J. Appl. For. 5: 70-77.

Hill, J.P., and Dickman, D.I. 1988. A comparison of three methods for naturally reproducing oak in southern Michigan. North. J. Appl. For. 5: 113-117.

Johnson, P.S. 1984. Responses of planted northern red oak to three overstory treatments. Can. J. For. Res. 14: 536-542.

Johnson, P.S., Dale, C.D., Davidson, K.R., and Law, J.R. 1986. Planting northern red oak in the Missouri Ozarks: A prescription. North. J. Appl. For. 3: 66-68.

Loftis, D.L. 1983. Regenerating southern appalachian mixed hardwood stands with the shelterwood method. South. J. Appl. For. 7: 212-217.

Loftis, D.L. 1990. A shelterwood method for regenerating red oak in the Southern Appalachians. For. Sci. 36: 917-929.

Lorimer, C.G. 1989. The oak regeneration problem: New evidence on causes and possible solutions. Forest Resource Analyses No. 8. Univ. of Wisconsin-Madison. 31 pp.

Minter, W.F., Meyers, R.K., and Fisher, B.C. 1992. Effects of tree shelters on northern red oak seedlings planted in harvested forest openings. North. J. Appl. For. 9: 58-63.

Potter, M.J. 1988. Tree shelters improve survival and increase early growth rates. J. For. 86: 39-41.

Pubanz, D.M., Lorimer, C.G., and Guries, R.P. 1989. Effects of understory control on survival and vigor of red oak seedlings beneath a shelterwood. pp. 300-301 in Proc. Seventh Central Hardwood Forest Conf. Rink, G., and C.A. Budelsky (eds.) Carbondale, IL. Gen. Tech. Rep. NC-132.

Tuley, G. 1985. The growth of young oak trees in shelters. Forestry 58: 181-195.

Tworkoski, T.J., Smith, D.W., and Parrish, D.J. 1982. Response of underplanted seedlings to canopy removal in upper Piedmont hardwood stands. pp. 185-188 in Proc. Second Biennial Southern Silvicultural Research Conf. Jones, E.P., Jr. (ed.) Gen. Tech. Rep. SE-24.

Tworkoski, T.J., Smith, D.W., and Parrish, D.J. 1986. Regeneration of red oak, white oak, and white pine by underplanting prior to canopy removal in the Virginia Piedmont. South. J. Appl. For. 10: 206-210.

Wright, G.M., Pope, P.E., Fischer, B.C., Holt, H.A., and Byrnes, W.R. 1984. Chemical weed control to establish natural and artificial oak regeneration in a mechanically thinned upland hardwood stand. pp. 266-272 in Proc. Third Biennial Southern Silvicultural Research Conf. Shoulders, E. (ed.) Gen. Tech. Rep. SO-54.

Group Selection—Problems and Possibilities and for the More Shade-intolerant Species

Paul A. Murphy, Michael G. Shelton, and David L. Graney[1]

Abstract: The group selection method is a hybrid, drawing key elements from both even- and uneven-aged silviculture. It is perhaps the least used and understood of all the reproductive cutting methods, but it is gaining popularity because of the current disfavor of even-aged silviculture. The group selection method appears promising for regenerating shade-intolerant and intermediate-tolerant species. Research has shown that larger openings create conditions favorable to shade-intolerant species, while smaller openings favor the more shade-tolerant ones. Larger openings consist of a central core that is relatively unaffected by the adjoining stand and a periphery with increasing levels of suppression. Operationally, most opening widths vary around one to two times the dominant tree height in the residual stand, but research has yet to verify the long-term stand dynamics within openings. Even less is known about effective stand-regulation options available to provide sustained yields. One route is to adapt stand structure or volume control from the single-tree selection system. An alternative is to use (1) the silvical requirements of the target species to set opening size and (2) area control to determine the number of openings to create each cutting cycle. This latter approach seems to have advantages for applications in even-aged stands that are being converted to uneven-aged ones.

INTRODUCTION

Group-selection cutting has been a much debated but heretofore little used reproduction method. It has been advanced as a viable technique and vilified as impractical and difficult to maintain. Marquis (1978) described group selection as a "bastard" technique that attempts to meld an even-aged reproduction cutting method with an uneven-aged silvicultural system. Roach (1974) called it a modification of single-tree selection to favor reproduction of less shade-tolerant species. Interest in the group selection method has been revived recently because of controversies surrounding even-aged reproduction methods, especially clearcutting, and the apparent shortcomings of the single-tree selection method for regenerating certain species.

Although clearcutting is a proven, efficient reproduction method for many species, its use has been sharply curtailed because of public sensitivities to the dramatic visual impact of a recent clearcut. This criticism of clearcutting has occurred not only in the United States, but also in other countries (Bradshaw 1992). The outcry about clearcutting on public lands has resulted in its complete abandonment in some cases and a more circumspect use in others--such as reducing the size, blending the cuts with the landscape, and masking their size by employing convoluted shapes. The other even-aged methods, seed tree and shelterwood, would seemingly ameliorate the drastic perturbation of clearcutting and still provide some of its efficiencies. However, they have suffered a "guilt of association" by being even-aged methods.

The single-tree selection method has been proposed as an alternative to clearcutting, especially by environmental groups, because it appears to be the antithesis of the much despised clearcutting.

---

[1] Principal Mensurationist, Silviculturist, and Principal Silviculturist, southern Forest Experiment Station, Monticello, AR.

However, it has limitations like any cutting method. If applied to even-aged stands, the smaller trees may be the same age as ones in the overstory and may not respond to release. Also, if practiced with no competition control, shade-intolerant species will be gradually replaced by shade-tolerant ones in the understory. This has been a common outcome with trials in eastern hardwoods.

The fallen repute of even-aged cutting methods plus the limitations of single-tree selection when administrative restrictions are imposed have made group selection the choice by default for many public lands. However, operational use has been virtually nonexistent until recently, and research has focused mostly on the establishment and development of regeneration within openings. Many questions have not been studied or only fragmentary information is available: how should the residual stand be managed; the distribution, optimum size, location, and shape of openings; the need for site preparation both in openings and the residual stand; and how the stands should be regulated. Opinion differs about what constitutes the group selection system and what regulation techniques are appropriate.

In this paper, we explore these issues by examining existing literature concerning what group selection is, how it differs from single-tree selection and closely allied even-aged cutting methods, how regeneration of desirable species might be obtained by appropriate opening designs and site preparation techniques, and the alternatives for stand regulation. We also focus on the application of group selection to the more shade-intolerant species, which are usually targeted in central and southern stands. Because of this focus, a broader definition of group selection has been adopted in this paper than has been proposed elsewhere (Marquis 1989, 1992).

CONCEPTS AND DEFINITIONS

We paraphrased the following definitions from Smith (1986):

> Even-aged stand—a stand that is composed of one or two age classes, and the range of tree ages in an age class does not span more than 20 percent of rotation length.
>
> Uneven-aged stand—a stand that is made up of at least three age classes, where an age class is defined as for even-aged conditions.
>
> Reproduction method—is how a stand is established or renewed. An uneven-aged cutting method will regenerate or create an uneven-aged stand.
>
> Silvicultural system—the planned sequence of silvicultural activities that are designed to create and/or maintain either even- or uneven-aged stands.
>
> Single-tree selection method—is a reproduction cutting method used to regenerate an uneven-aged stand and consists of removing mature trees as scattered individuals or as small groups at relatively short intervals.
>
> Group selection method—is a reproduction cutting method used to regenerate an uneven-aged stand by removing groups of adjacent trees at relatively short intervals.

From these definitions, the group selection system includes the following: (1) using the group selection method to create new age classes, (2) applying appropriate site preparation, release of advance regeneration, or tending of immature trees within openings, (3) tending the remainder of the stand, and (4) employing a regulation technique to assure a balanced structure and sustained yield.

Group Selection vs Single Tree Selection

If a strict interpretation is made of the definitions of single tree and group selection, then the single-tree method involves removal of scattered mature trees, and the group selection method entails the removal of two or more adjacent mature trees. Nyland (1987) makes this distinction for northern hardwoods. However, harvest of only mature trees (whether they occur singly or in groups) may not result in openings that are large enough to meet the silvical requirements of the target species, especially the more shade-intolerant ones.

Marquis (1989, 1992) has a somewhat different interpretation of group selection as applied to northern hardwoods. Group openings are created in areas where several trees need to be cut for quality, size, vigor, or other factors; they need not be mature. The openings are usually small, about 0.1 to 0.25 acres, but may occasionally reach 0.5 acres. Groups are made to increase the representation of shade-intolerant species, but not necessarily to maximize their percentage.

We prefer to focus on how mature trees are selected for harvest as a way to differentiate between the single tree and group selection methods. In single tree selection, trees are selected for harvest largely based upon their individual merits, such as financial or biological maturity. Because trees tend to occur in small, similar clumps, a group of trees may be cut under single-tree selection, but each tree was chosen individually.

The single-tree selection system has been successfully adapted to more shade-intolerant species, such as the loblolly-shortleaf pine type (*Pinus taeda* and *P. echinata*, respectively), by following certain principles and practices: (1) a target species or species mixture that is moderately tolerant in the seedling stage, (2) maintaining a residual basal area low enough to permit the establishment and development of desired reproduction, (3) choosing a cutting cycle to keep basal area levels within acceptable ranges, (4) eliminating overstory and midstory non-target competition by harvesting or manual and/or chemical treatment, and (5) periodically controlling understory non-target competition (usually with selective herbicides). The combination of a low basal area (one that does not exceed 75 square feet per acre at any time during the cutting cycle) and competition control results in an environment favorable for development of pine regeneration.

Under these conditions, a quite different forest mosaic occurs than the popular conception of a continuous forest cover with an occasional small opening created by the removal of a single tree. For example, the canopy is quite irregular and broken in loblolly-shortleaf pine stands managed under the single-tree selection system. Immature clumps of pines are interrupted by groups of pulpwood and sawtimber, occasional lone specimens of larger trees, and recently created openings that can range up to 0.5 acres in size. According to a strict interpretation of the definitions, both single tree and group selection methods have been used under this management. But we think that this strict interpretation results in a misleading explanation of the system. A combination of both stand structure control and a low residual basal area results in the creation of gaps or openings of various sizes. However, these openings were not purposely created by consciously trying to create an opening at a specific location.

In the group selection method, the choice of trees for harvest focuses on groups of trees rather than individuals. Groups are selected for harvest based on their aggregate condition: Are most of the trees in the group financially mature? Should they be removed because of damage inflicted on the group? Are most of the trees likely to die if they are not cut now? Is the group poorly stocked with little likelihood of becoming well stocked with the existing trees? According to this interpretation, selection of a group includes not only mature trees but also other trees within the area.

The choice of single-tree versus group-selection depends upon how the advantages of each cutting method fits management objectives. The advantages of single-tree selection are: (1) regulation is easier, (2) better visual quality because of absence of large openings, (3) greater stand homogeneity, and (4) possibly a better yield and quality of timber. Group selection has the following advantages: (1) provision of better regeneration microsites, (2) herbicide applications can be confined to less area, (3) more intensive site preparation can be used, (4) existing regeneration is easier to protect, (5) a diversity of habitats for plants and wildlife is created, and (6) mixed-species stands (especially intolerant-intermediately tolerant mixtures) are easier to maintain.

Group Selection vs Patch Clearcutting

Group selection might also be confused with clearcutting that is confined to small areas of several acres. Though these even-aged stands might be small, they will retain their integrity, and a silvicultural program for these stands will be a sequence of well defined activities suitable for even-aged stands. For administrative purposes, their identity will be preserved by silvicultural treatments and mapped as regenerated for regulation purposes. In contrast, the location of openings in group selection is not known. In addition a principal goal of group selection is to create an uneven-aged stand with its characteristic reverse J-shaped stand structure.

If openings exceed 0.5 acres in size in northern hardwoods, Marquis (1989, 1992) states that the resulting environments become more like those in clearcuts, and he calls the system patch cutting. Smith (1980) makes a similar interpretation for central Appalachian hardwoods. However, differentiating between group selection and even-aged methods based upon only opening size is somewhat arbitrary. Bradshaw (1992) proposed that the distinction lies in the proportion of the opening that is influenced by edge effect. Openings in uneven-aged silviculture are dominated by edge effect, while the unaffected core dominates the openings of even-aged silviculture. The extent of edge effect depends on the opening size and shape, the height of the residual stand, the silvical requirements of the target species, and topography.

Perhaps a better limit might be scaling opening size according to the residual stand height. Smith (1986) has suggested openings whose diameter is twice the height of the surrounding stand. If this limit is accepted as a guide, then openings could reach up to an acre in size in eastern forests (Figure 1). However, most openings will probably be smaller because stand heights will typically be less than 100 feet. Thus, adopting two times the height of the surrounding stand as the upper limit for group selection may result in slightly larger openings than the 0.5 acre limit proposed by Marquis (1989). Openings that far exceed this limit of two tree heights are being created for administrative efficiency, logging costs, or other reasons; the rationale for opening size has ceased to be motivated by environmental conditions.

The silvical requirements of target species must also be considered in determining a suitable opening design. Some shade-intolerant species may need openings somewhat larger than two times tree height to provide an acceptable distribution of edge effect, while more shade-tolerant species may require smaller openings. In application, opening size and configuration is a compromise between the existing group of trees and the regeneration requirements of the desired species. For example, the size of the extant group might be 0.2 acres, but the silvical characteristics of the species might require a larger opening.

As noted by Minckler (1986, 1989), some foresters think of group selection as a mechanical placement of openings up to 2 acres in size with openings near the upper size limit being generally favored. Clearly, such a systematic arrangement of openings is not based upon stand conditions and may not address the silvicultural needs of the stand.

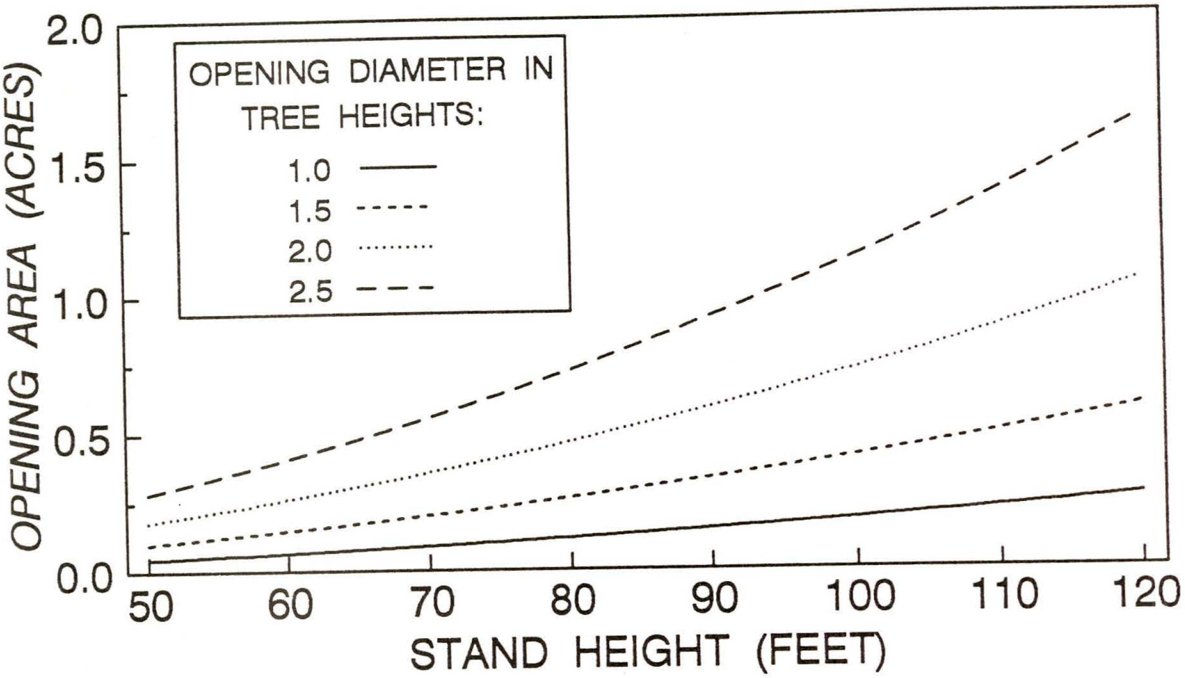


Figure 1.—Group opening size as affected by surrounding stand height and required opening diameter.

Variants of Group Selection

The group selection system may be viewed as a whole suite of variations that can be separated only with difficulty and by use of a complicated terminology (Smith 1986). Such variation taxes our silvicultural nomenclature but adds flexibility to the system. Vigorous, immature trees can be left in the openings as future growing stock, while removing low-quality material (Minckler 1986, 1989). Seed trees might also be retained much as in the seed tree or shelterwood methods. These trees enhance seed production, provide shelter, and improve visual properties.

REGENERATION

Opening Size, Shape, and Location

A basic concern in applying the group selection method is the opening size necessary to secure acceptable reproduction of desired species. Most past research focused on the development of reproduction within openings. It has clearly shown that shade-intolerant species develop better in large openings and that shade-tolerant species dominate small openings (Bradshaw 1992).

The area within an opening that is influenced by the surrounding stand depends on: (1) size, shape, and orientation of the opening, (2) height, density, and species composition of the edge trees, and (3) slope and aspect. Marquis (1965) reported that shape and orientation have little effect on the average exposure to direct sunlight occurring in 0.1-acre openings, with values ranging only from 22 to 26% (Figure 2). However, shape and orientation had an important effect as opening size increased. For 0.5-acre openings, a rectangular shape with north-south orientation has the lowest average exposure to direct sunlight (44%), while one with an east-west orientation

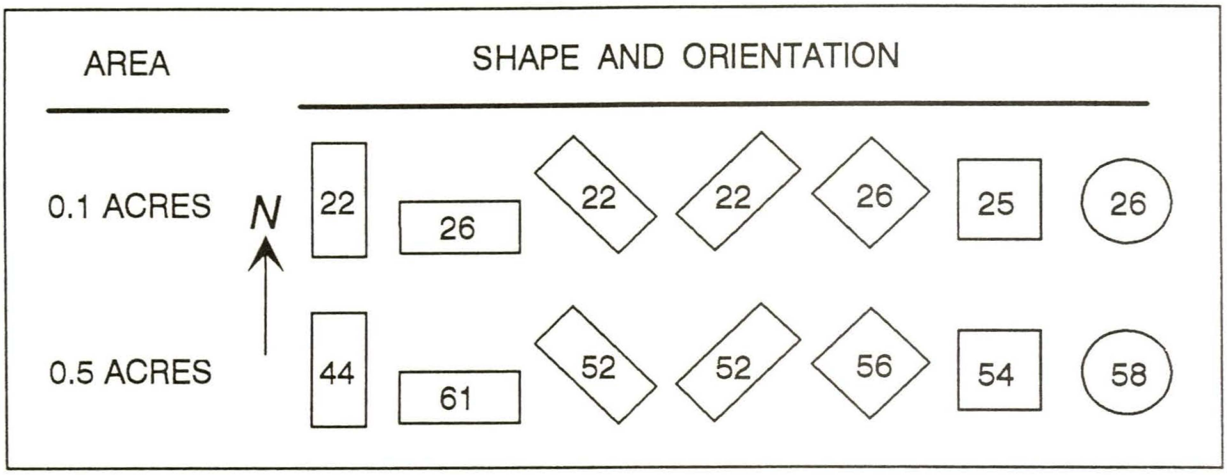


Figure 2.—Average direct sunlight exposure (percent) occurring in various opening sizes, shapes, and orientations (after Marquis 1965).

had the greatest (61%). Thus, narrow openings with a north-south orientation may not create light conditions necessary for shade-intolerant or intermediate-tolerant species. Describing the effects of slope on the direct solar radiation occurring in openings, Fischer (1979) found that values for a 30% slope on a north aspect were about one-third less than for an identical slope with a south aspect. Thus, north-aspect openings need to be larger than ones on a south aspect to have comparable values of solar radiation. In application, openings with straight boundaries and angular corners have harsh visual properties, and preferred shapes are circles, ellipses, ovals, teardrops, kidneys, and amebas.

Opening size and shape affect reproduction survival and growth of shade-intolerant species, such as loblolly and shortleaf pine (Wahlenberg 1960; Jackson 1959). Survival and height growth are greatest in larger openings, and circular openings have higher values than irregular ones (Figure 3A and 3B). Wahlenberg (1960) reported that the edge of a young sawtimber stand influenced the development of reproduction up to 30 feet into adjacent openings. Six-year-old seedlings beyond 30 feet from edge trees were twice as tall as those within 10 feet (4.5 versus 9.1 feet). The amount of an opening unaffected by edge trees increased with opening size, and was 4 to 12 times greater in circular openings than irregular ones of the equivalent size (Figure 3C). Thus, small circular openings provide a better environment for shade-intolerant reproduction than much larger ones of irregular shape. A 0.8-acre circular opening has one half of its area affected by surrounding trees; smaller openings are dominated by this edge effect, while larger openings are dominated by the unaffected core (Figure 3C).

Advance oak reproduction growth in the center of openings with diameters as small as one or two tree heights is similar to that observed in large clearcuts (Minckler and Woerheide 1965; Sander and Clark 1971; Smith 1980, 1981). However, smaller openings have a high proportion of area affected by edge trees and will hinder the development of the more shade-intolerant species (Sander and Clark 1971; Sander and others 1983; Smith 1981).

Finding opportunities to create openings within a stand requires paying close attention to stand conditions and terrain features. Unless stand conditions are very uniform, openings should not be mechanically spaced. Opening location should be based on both overstory and understory conditions. Suitable locations include: (1) groups of mature trees, (2) areas with poor stocking and/or low quality trees, and (3) areas with good advance reproduction, especially for the oaks.

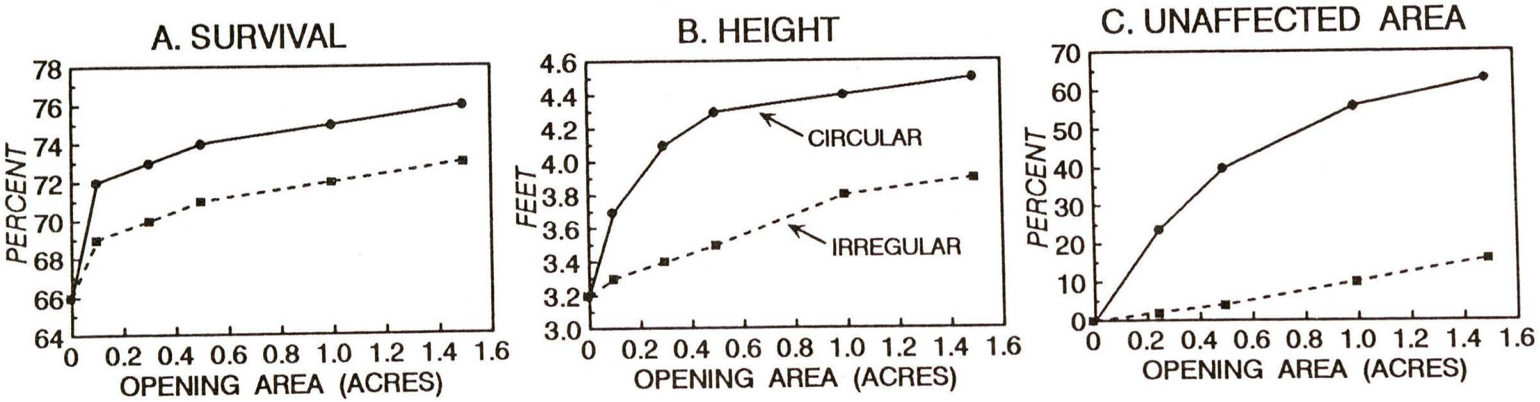


Figure 3.—Effect of opening size and shape on (A) survival and (B) height of 5-year-old pine regeneration and (C) the percent of total area unaffected by the surrounding stand of young pine sawtimber (after Wahlenberg 1960).

Reproduction Options

The group selection method establishes openings in the canopy to create a favorable environment for desired species. Successfully regenerating these openings is critical for long-term stand sustainability. A principal factor affecting reproduction success is the shade tolerance of the targeted species.

Shade-Intolerant Species

The group selection method seems to have potential for regenerating a wide variety of the more shade-intolerant species, such as ashes (*Fraxinus* spp.), black cherry (*Prunus serotina*), loblolly pine, shortleaf pine, sweetgum (*Liquidambar styraciflua*), and yellow-poplar (*Liriodendron tulipifera*). These species typically regenerate from wind-disseminated seeds and grow poorly in the shade. They frequently regenerate naturally in the resource-rich environments existing after major stand disturbances. Reproduction can develop from several sources depending on (1) when a disturbance occurs, (2) the annual variation in seed production, and (3) the species silvical characteristics. Possible sources include in-place seeds, seeds disseminated by nearby trees, advance reproduction, and stump sprouts for some species. Reproduction from in-place seeds is important for species such as yellow-poplar, whose seeds remain viable for 4 to 7 years in the forest floor (Clark and Boyce 1964). For species with short-lived seeds, reproduction from in-place seeds will be opportunistic, and most reproduction will probably come from seeds dispersed from nearby trees while seedbed conditions remain receptive. Thus, an adequate seed source of desirable species is usually important when locating openings. The maximum down-wind seed dispersal for acceptable reproduction is 200-300 feet for loblolly pine (Pomeroy 1949), 200 feet for sweetgum (Kormanik 1990), and 200 feet for yellow-poplar (Beck 1990). Consequently, wind-disseminated seeds should adequately regenerate the central portion of the largest openings proposed under the group selection method if there is a seed source. Animal dissemination will be crucial for certain shade-intolerant species, such as black cherry.

Surface disturbance enhances the seedbed conditions for some shade-intolerant species, such as loblolly and shortleaf pines. For such species, skid trails could be routed through openings if terrain and soil features are not limiting. Although successful natural reproduction can be obtained with logging conducted anytime during the year, the optimum time is just before seed dispersal, which assures a receptive seedbed.

Planting is a viable option within openings where conditions do not favor natural reproduction (Waldrop 1991). However, costs per unit area may be higher than for typical even-aged operations, because of inefficiencies associated with planting small scattered openings. Direct seeding may also be an alternative for some species (for example, the pines).

Intermediate-Shade Tolerant Species

Group selection method has potential for regenerating species of intermediate-shade tolerance, such as oaks (*Quercus* spp.) and hickories (*Carya* spp.). We will focus on the oaks because they are the premier representatives of these heavy-seeded species. Natural oak reproduction in both openings and in the residual stand will consist of new seedlings, advance reproduction (older seedlings and sprouts), and stump sprouts of harvested trees. New seedlings are not a viable source of oak reproduction, because they grow too slowly and other vegetation usually overtops them within a few years (Beck 1970; McQuilkin 1975; Sander 1972). Thus, well-developed, advance oak reproduction or small stems with sprouting potential must be present before overstory removal if oaks are to become an important component in the new stand. Height growth of oak stump sprouts is rapid, and they usually grow into upper crown positions in the new age class after overstory removal (Johnson 1977, 1979). However, the probability that an oak stump will produce a dominant or codominant stem decreases with increasing tree diameter and age (Johnson 1977). Stump sprouts can be an important source of oak reproduction in many upland hardwood stands on medium and poor sites. Mature stands on these sites usually contain a relatively large number of small-diameter oak stems that will sprout after cutting. By contrast, mature stands on more productive sites have few small-diameter oaks, and the larger trees will not sprout sufficiently to regenerate an adequate oak component after cutting.

In most cases, advance reproduction will be the primary source of any dominant and codominant oaks that develop in openings. However, the presence of advance oak reproduction alone does not guarantee success. Advance reproduction must be relatively large and have well-established root systems (Carvell 1979; Sander 1972, 1988; Sander and Clark 1971). Growth of advance reproduction following cutting is strongly related to its size before harvest (Sander 1971, 1972). The probability that an individual oak stem will become a dominant or codominant increases with increasing basal diameter and height, but even larger stems may not succeed on higher quality sites (Loftis 1990a; Sander and others 1984).

Advance oak reproduction must also be established throughout portions of the stand for future openings. Proposed procedures are similar to the shelterwood method for oaks, and involve regulating overstory stocking and controlling midcanopy and understory competition (Sander 1987, 1988; Loftis 1990b). The time required to establish oaks and grow them to an adequate size as advance reproduction is not known, but could vary from 2 to 20 or more years. Where natural oak advance reproduction is inadequate, planting can supplement existing reproduction within the stand or in poorly stocked openings. A technique developed for the Missouri Ozarks involves planting large caliper 2-0 stock under a shelterwood overstory 3 to 5 years before overstory removal. Subcanopy control is needed at planting, and on productive sites a second treatment may be required at the time of overstory removal (Johnson 1984; Johnson and others 1986).

Another approach currently being tested is the placement of plastic sleeves, or tree shelters, around planted seedlings. Tree shelters protect seedlings from browsing and improve the microclimate within the shelter. Their use with oak planting in Britain has quadrupled height growth in the first 4 years (Potter 1988).

Effects of the edge trees may complicate the evaluation of oak reproduction potential in openings. Present guidelines were developed for large clearcuts (Loftis 1990a; Sander and others 1984) and may not suffice for smaller openings. Successful development of oaks in smaller openings may require larger advance reproduction than necessary for clearcuts and/or more intensive competition control.

Mixed-Species Stands

Compositional gradients will likely develop within openings, with shade-intolerant species dominating the opening center and the more tolerant species dominating the edge. This may be a blessing or a curse depending on silvicultural objectives. The natural segregation of species across an opening would be ideal in establishing pine-hardwood mixtures, due to their differential growth rates. Pines tend to dominate natural even-aged stands, where overstocking frequently occurs. A pine-hardwood composition could also be favored by establishing a range of opening sizes, with the pines tending to dominate the larger openings and hardwoods the smaller ones.

Competition Control

Without species control, the application of uneven-aged silviculture in stands of the more shade-intolerant species will usually cause a gradual shift in composition to more shade-tolerant ones.

This is a major limitation in using this system to create or maintain in uneven-aged stands of the more shade-intolerant species (Blair and Brunett 1976; Franklin 1978). Competition control may help to preclude this species shift.

Operational application of competition control has not been widely tested in small scattered openings. Undoubtedly, it will be less efficient than stand level-treatments, and contractors will need compensation for the time required to locate and travel between openings. Locating openings will be easiest in the first dormant season following logging when visibility is a maximum. There is also some potential to link the harvesting operation and control of unwanted submerchantable trees by either chain-saw felling or using skidders as shears. The extent to which manual and mechanical methods can be substituted for herbicides is unknown, especially on better sites.

Shade-Intolerant Species

Competition control for species regenerating from seed should occur after the logging and be limited to well-defined openings. It may be required every cutting cycle. The need for competition control in openings will vary with seed production, merchantability of small trees, harvest volumes, and understory condition. Because harvest volumes in group selection cutting are more concentrated, seedbed disturbance from logging will typically be greater than with single-tree selection cutting. Logging will often provide sufficient surface disturbance to establish adequate stocking of shade-intolerant species requiring a scarified seedbed, although subsequent release may be required. In addition to treating current openings, release work may be required in previously established openings. Broadcast applications of selective herbicides are an option in pine stands. However, competition control for shade-intolerant hardwoods or pine-hardwood mixtures will be limited to individual-stem treatments.

Intensive mechanical methods of site preparation can be used within group openings for both seedbed preparation and competition control (McDonald and Fiddler 1991). However, they should probably be restricted to stands with severe competition problems, because excessive stocking may occur.

Intermediate-Tolerant Species

Competition control involves treating portions of the residual stand to secure the advance oak reproduction needed for future openings, as well as releasing advance reproduction in the openings. Competition control can include a full array of herbicide treatments of individual stems--basal and foliar sprays and cut-surface applications. Operators must be able to identify the tree species targeted for control.

Competition control in the residual stand is similar to that done in the shelterwood method. Treatments must be intensive due to the slow response of oak reproduction and the rapid development of other species (Hannah 1987). Recommendations for shelterwood stands in the southern Appalachians call for killing all noncommercial stems larger than 0.6 inch d.b.h. (Loftis 1990b). On highly productive sites, this will yield relatively few dominant or codominant oaks but will ensure an oak component in the new stand. For productive mesic sites in the Central hardwood area, competition control may have to be even more intensive. Sander (1987, 1988) recommends killing at least the competitors more than 6 feet tall, but preferably all competitors.

The need to release oak reproduction will depend on the intensity of previous competition control measures, opening size, and site quality. Intensive competition control applied years before creating openings may reduce or eliminate the need for later treatments. If there is adequate large oak advance reproduction, cutting or killing stems larger than 1 or 2 inches dbh should suffice (Sander 1988). More productive sites may require more intensive competition control. In small openings, the edge trees may retard oak reproduction growth, which might reduce oak stocking. This may necessitate more intensive release, especially on the more productive sites.

Protection

The selection system involves periodic harvest of mature trees intermingled with younger trees, and logging will damage or destroy some of them. This potential damage has long been recognized in uneven-aged stands where multiple size classes are interspersed (MacKinney 1934). Damage was of little concern during the days of animal skidding or small skidders. However, current emphasis on logging efficiency (large skidders and tree-length logging) has raised the specter of more severe damage to both reproduction and merchantable trees. The group selection method offers some degree of protection by concentrating reproduction to well-defined openings (Guldin 1991). Logging contracts could be written to preclude logging activity in areas with young reproduction. In highly controlled circumstances, a limited amount of skidding through openings overstocked with reproduction might be used for precommercial thinning. Skidding damage can also be important in the residual stand, especially in hardwoods where damage to the lower bole can result in rot and other defects that can reduce tree value.

Because of the intermingled size classes, fire protection is critical in uneven-aged stands of either pine or hardwood. However, an interrupted-prescribed burning cycle could potentially be used in pine stands under group selection if long cutting cycles are used (Chapman 1942). Prescribed fires could start as soon as reproduction within openings reaches fire-tolerant sizes, and burning would stop when a new series of openings are created. However, because of the heterogeneous stand conditions, the use of prescribed fire will never be as simple as in even-aged stands.

REGULATION

Regulation in uneven-aged stands is a complex topic, and our goal here is to briefly discuss its role in uneven-aged silviculture and how it can be used in the group selection system.

We begin with some definitions adapted from Davis and Johnson (1987):

> Regulation—as it is traditionally defined is the management of a forest to provide a sustained, even flow of timber or other products. However, regulation is also applied at the stand level in the selection system.
>
> Area control—is a method of regulation in which a sustained yield is provided by harvesting and regenerating the same amount of area each period.
>
> Volume control--is a method of regulation in which the harvested volume for each period is based upon the growing stock level and its distribution and growth. A growing stock level is chosen so that a sustainable periodic cut is achieved.

A fully regulated forest has been regarded as one in which a sustained and even yield has been achieved in perpetuity. Both Davis and Johnson (1987) and Smith (1986) state that the whole concept of regulation has become more flexible, because (1) most landowner objectives change with each planning period and (2) many forests are managed to provide both a flow of timber and other forest products under performance criteria and constraints that often change.

Both area and volume control have been used for even-aged forests. Area control can provide a fully regulated condition by the end of one rotation, but annual yields during the conversion period may vary. If relentlessly pursued, other landowner objectives may be sacrificed to achieve a fully regulated forest. Volume control ameliorates fluctuating yields by providing more stable harvests, but a fully regulated condition may not be achieved in one rotation. In practice a combination of the two methods has been used, and modern scheduling techniques have further blurred the distinction between them.

Uneven-aged stands maintained by single-tree selection have been traditionally regulated by volume. According to Smith (1986), it might be more appropriately called regulation by diameter distribution or stand table. Although Smith states that "the volume method of regulation is really a sophisticated and indirect way of applying the area method", area control has not been used at the stand level. However, area control is used for regulating uneven-aged stands in a forest by guiding the amount of area that is to be scheduled for cutting each year or period (Davis and Johnson 1987). For example, a forest of 1,000 acres on a 5-year cutting cycle might have 200 acres scheduled for cutting each year.

The only long-term study of the group selection method that we could find was reported by Leak and Filip (1977). A 114-acre tract of New England hardwoods on the Bartlett Experimental Forest in New Hampshire was cut using group selection for 38 years on a 9-14 year cutting cycle starting in 1937; no cutting occurred between group openings. This cutting resulted in a reverse J-shaped stand structure typical of uneven-aged stands. Their conclusion was that group selection improves species composition by regenerating less shade-tolerant species and maintains stand conditions similar to those recommended for single-tree selection. They recommended that the group-selection method be used to provide for regeneration and the single-tree selection method to remove trees in the remainder of the stand. Leak and Filip expressed doubts that area regulation could be used because the groups were hard to identify after several years.

In a comprehensive discussion about group selection, Roach (1974) describes it only as a reproduction cutting method and not a silvicultural system. Roach asserts that regulating uneven-aged stands depends upon maintaining a balanced diameter distribution and that this distribution is achieved by controlling the density in three grouped basal area classes—such as pulpwood, small sawtimber, and large sawtimber. This is possible in stands under single-tree selection, because size classes are uniformly intermingled within the stand. But Roach maintains that group-selection cutting makes the stand more fragmented as more openings are created, then it becomes impossible to maintain a mental image of their dispersement throughout a stand. Thus, marking by size classes becomes difficult.

Roach concludes that there are only two ways to use group selection and maintain a sustained yield. One is to make groups very small so that stand variability is not increased and the stand can be regulated by stand structure. The other option is to make the openings large enough to use area control. If group selection is uncritically adopted, he warns that large fluctuations in yields will occur. If the requirement for sustained yield is relaxed, Roach relents and says that group selection might be used for aesthetic and environmentally sensitive areas and small private properties where there is not an overwhelming need or desire for sustained yield.

Other authors (Alexander and Edminster 1978; Gibbs 1978; Marquis 1978, 1989; Guldin et al. 1991) have echoed Roach's conclusion that stand structure control is the only regulation technique for uneven-aged silviculture. Foiles (1978), however, mentions the conversion of old-growth stands of ponderosa pine and Douglas-fir to uneven-aged ones by using a combination of both area and volume control. Boucher and Hall (1989) describe a procedure for implementing group selection in Appalachian hardwoods using economic guidelines.

Heald and Haight (1979) describe a procedure for managing naturally occurring vegetation groups in California's mixed conifer-oak stands. They classify these natural groups into six size classes (defined by tree diameter), regulate each group by basal area and spacing guides, and harvest and regenerate the groups when the general tree size exceeds a prescribed maximum diameter. A goal is to have these six size classes occupy approximately equal areas, but no attempt is made to keep track of group location.

Law and Lorimer (1989) describe a methodology for regulating uneven-aged stands of Central hardwoods. They use stand-structure regulation by specifying (1) a residual stand table; (2) a cutting cycle length; (3) opening sizes required by aspect and slope for successful oak regeneration; and (4) number of openings required by aspect, opening size, and residual stand table. The number of openings is based on the average area occupied by a 2-inch sapling at a B-stocking level (Ginrich 1967) and the number of trees in the 2-inch class for different stand structures. Thus, all the stand except for current group openings is regulated by a diameter distribution.

Marquis (1989) states that openings larger than 0.5 acres are difficult to regulate by volume or structural control. Thus for patch cutting, he recommends that the total area in new patches during each cutting cycle be based on the cutting cycle length and the length of an equivalent even-aged rotation. The residual stand would be tended by using thinning with no structural goal. Marquis (1989) concludes that this system will create uneven-aged conditions using even-aged techniques.

Critique

Group selection has some difficulties, especially as openings are created over several cutting cycles. As Roach (1974) stated, the stand becomes more heterogenous as more and more of the stand area becomes occupied with older group openings. After several cutting cycles, locating areas suitable for openings becomes more difficult. Unfortunately, our experience with the long-term consequences of group selection is virtually nil, except for the observations of Leak and Filip (1977). Therefore, many conclusions about stand irregularity and operational problems are speculative and hypothetical.

Roach's views (1974) had a strong impact on subsequent discussion of group selection, especially about sustained yield and regulation techniques. However, he did not discuss the impact of silvical requirements on opening size and how it must be incorporated into converting and regulating stands using group-selection cutting. An insistence that volume or stand-structure regulation is the only valid regulation method for uneven-aged stands appears to be unduly restrictive, and may be a consequence of the emphasis on stand-structure regulation with single-tree selection. However, area control may have a role in group selection.

Problems might arise when an exclusive reliance on stand-structure control is made in stands that have poor structure, such as mature sawtimber stands. Some guidance is needed to allocate the cut between the harvest cuts (the group openings) and stand tending (cutting in the residual stand for thinning, improvement, sanitation, etc). Otherwise, the total cut could be concentrated in openings at one extreme or in the residual stand itself at the other extreme with no openings being created. Law and Lorimer (1989) explicitly offer a solution to the problem of integrating group selection with stand regulation. They specify the number of group openings for Central hardwoods that might be made for a 15- to 20-year cutting cycle; openings represent about 3 to 9 percent of the total area. Although based on structure, any procedure that generates the number and size of openings is close to area control. Another approach would be to use area control directly.

Regulation Alternatives

How can a modification of area control be used for regulation and how can the opening size requirements of the species under management be integrated? Some guidelines can be adapted from even-aged management and follow Marquis' (1989) recommendations for patch cutting. We could assume that the harvested groups of mature trees would be approximately the same age as trees in an even-aged stand at rotation age, and this age would be the length of the conversion period required to fully regulate the stand. Opening size would depend upon the silvical requirements of the species and the stand height surrounding the opening. A cutting cycle length is chosen so that operable cuts can be made based upon the growth rates of trees in the stand and that suits the silvical requirements of the target species. The area in openings (OA) can be calculated from stand area (SA), conversion period (CP), and cutting cycle length (CC) by the following: $OA = CC(SA/CP)$. The number of openings (N) is determined by dividing the area in openings by the average opening size (OS), or $N = OA/OS$. The advantages of this approach over Law and Lorimer's (1989) is that it is more direct, simpler to calculate, and is sensitive to the cutting cycle length. It seems appropriate that the acreage in openings should increase as cycle length is lengthened. Area regulation also seems to be appropriate for applications in even-aged stands that are being converted to uneven-aged ones. This is especially true during the early part of the conversion effort, when opening locations are easy to select. Regulation might switch to volume or structure later in the conversion period when multiple age classes exist.

The allocation of area to group openings just covers the reproduction method, and some consideration must be given to stand tending. Law and Lorimer's solution is to use stand structure for regulation, and their technique would seem to work well in stands where the smaller, subordinate trees are vigorous and the preferred species. However, if these subordinates are suppressed, poorly formed, or less preferred species, then their procedure would seem inappropriate. Such trees lower the quality of the residual stand, which violates a basic tenet of always improving stand quality. Figure 4 shows that most crop trees are in the larger diameters of a representative upland oak stand in the Boston Mountains of Arkansas. A strict application of structure control would leave the stand in poorer condition.

An alternative in such stands is to subject the residual stand to a free thinning to a prescribed basal area and rely on regeneration in openings to create uneven-aged structure. Although intriguing, this method, as with others, has not been tested in group selection. Unfortunately, the feasibility of any technique will have to be verified with long-term studies. Another approach might use computer simulation, but our present understanding of stand dynamics under these conditions is abysmal.

We are presently installing a study in upland oak stands in the Boston Mountains which tests these alternatives. We used two residual stand densities (65 and 85 ft^2 per acre) and two stand regulation procedures (free thinning versus structure control). The study includes two different aspects and is replicated three times. The whole study is composed of twenty-four 7.2-acre plots, in which detailed tree and reproduction measurements will be conducted. A group opening will be created on each plot every 10 years to mimic regulation on an operational scale. This study should provide a great deal of insight into how stands will respond to long-term group-selection cutting and provide answers about regulation strategy.

CONCLUSIONS

Group selection is a hybrid, blending elements of both even- and uneven-aged silvicultural systems. It seems particularly well suited for the middle ground, where administrative constraints preclude even-aged silviculture and restrict key elements of uneven-aged silviculture, such as periodic competition control, and it holds promise for regenerating the more shade-intolerant

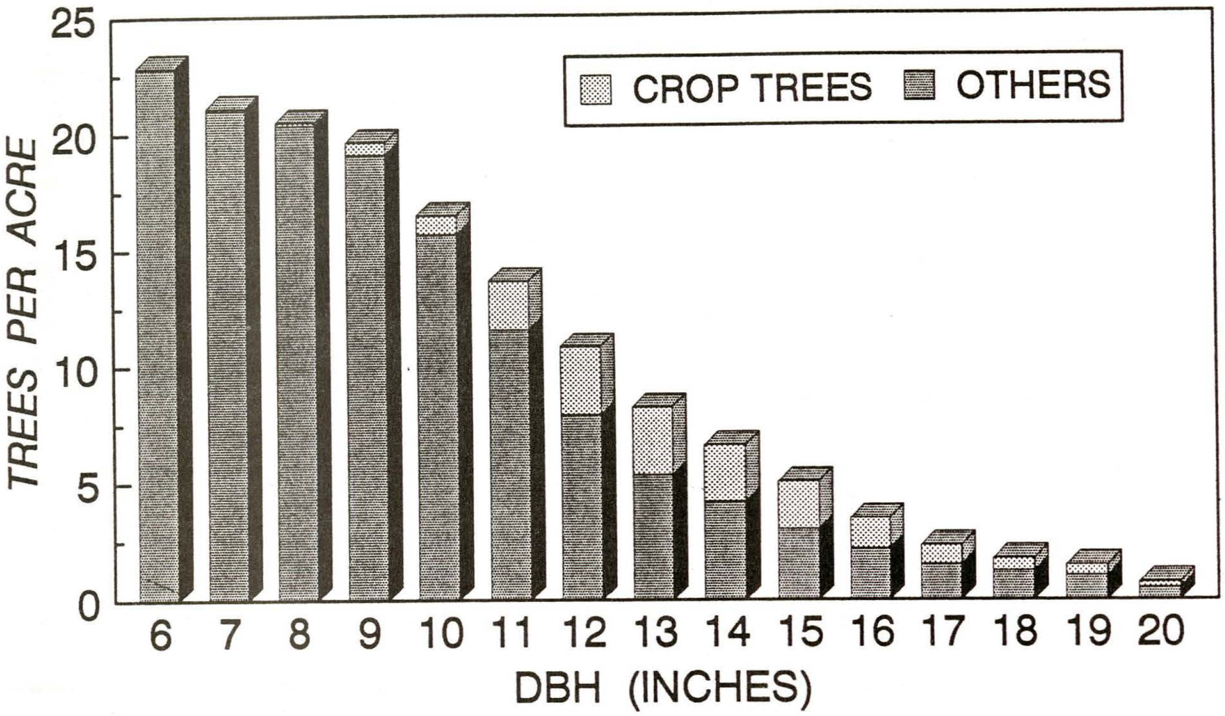


Figure 4.—Composite stand table of upland oaks by tree class in Boston Mountains of Arkansas (unpublished data, USDA Forest Service, Southern Forest Experiment Station, Monticello, AR).

species. Group selection will likely work best where natural regeneration is easily secured, landowners do not have a strong preference for species composition, and developing stands do not require much tending. Group selection is not without problems. The most pressing are (1) the inefficiency of applying silvicultural treatments to scattered openings and (2) stand variability--which increases the complexity of inventory, regulation, and prescriptions. Applications in oak stands are further complicated by the need to secure large advance regeneration.

Much of what has been written about group selection and feasible regulation alternatives is speculative (our paper included), because of the paucity of past research. A rejection of using area regulation seems to be due to the intimate association of volume or stand structure control with single-tree selection. However, this rejection does not seem to be justified, and using area control in conjunction with structure control for the residual stand appears to be a feasible alternative. We should also remind ourselves of the idea conveyed by Smith (1986) and Davis and Johnson (1987) that actual management does not depend upon strict dependence on classical regulation techniques. Incorporation of owner objectives and the use of modern management tools give foresters better, more flexible techniques to manage forests. As our understanding of group selection grows, we can also use these techniques for this much neglected cutting method.

ACKNOWLEDGEMENTS

Work was done in cooperation with the Department of Forest Resources and the Arkansas Agricultural Experiment Station, the University of Arkansas at Monticello. We appreciate the constructive

comments of Donald E. Beck, James M. Guldin, Ralph D. Nyland, and an anonymous reviewer. Nonetheless, the views expressed here are our own.

LITERATURE CITED

Alexander, R.R. and C.B. Edminster. 1978. Regulation and control under uneven-aged management. P. 217-230 in Combined proceedings on uneven-aged silvicultural in the United States. USDA For. Serv. Gen. Tech. Rep. WO-24.

Beck, D.E. 1970. Effect of competition on survival and height growth of red oak seedlings. USDA For. Serv. Res. Pap. SE-56.

Beck, D.E. 1990. Liriodendron tulipifera L. Yellow-poplar. P. 406-416. in Silvics of North America: Volume 2. Hardwoods. R.M. Burns and B.H. Honkala (tech. coords.). USDA Agric. Handb. 654.

Blair, R.M. and L.E. Brunett. 1976. Phytosociological changes after harvest in a southern pine ecosystem. Ecology 57:18-32.

Boucher, B.A. and O.F. Hall. 1989. Implementing group selection in Appalachian hardwoods using economic guidelines. P. 221-230 in Proceedings of the seventh central hardwood conference. G. Ring and C.A. Budelsky (eds.). USDA For. Serv. Gen. Tech. Rep. NC-132.

Bradshaw, F.J. 1992. Quantifying edge effect and patch size for multiple-use silviculture--a discussion paper. For. Eco. and Manage. 48: 249-264.

Carvell, K.L. 1979. Factors affecting the abundance, vigor, and growth response of understory oak seedlings. P. 23-26 in Regenerating oaks in upland hardwood forests; 1979 John S. Wright Forestry conference. H.A. Holt and B.C. Fischer (eds.). Purdue Res. Found., West Lafayette, IN.

Chapman, H.H. 1942. Management of loblolly pine in the pine-hardwood region in Arkansas and in Louisiana west of the Mississippi River. Yale Univ. Sch. For. Bull. 49:1-150.

Clark, F.B. and S.G. Boyce. 1964. Yellow-poplar seed remains viable in the forest litter. J. For. 62:564-567.

Davis, L.S. and K.N. Johnson. 1987. Forest management. 2nd ed. McGraw-Hill, Inc. New York.

Fischer, B.C. 1979. Managing light in the selection method. P. 43-53. in Regenerating oaks in upland hardwood forests; 1979 John S. Wright Forestry conference. H.A. Holt and B.C. Fischer (eds.). Purdue Res. Found., West Lafayette, IN.

Foiles, M.W. 1978. Stand structure. P. 176-185. in Combined proceedings on uneven-aged silviculture in the United States. USDA For. Serv. Gen. Tech. Rep. WO-24.

Franklin, Jerry F. 1978. Effects of uneven-aged management on species composition. in Combined proceedings on uneven-aged silviculture in the United States. USDA For. Serv. Gen. Tech. Rep. WO-24.

Gibbs, C.B. 1978. Uneven-aged silviculture and management? Definitions and differences. P. 18-24. in Combined proceedings on uneven-aged silviculture in the United States. USDA For. Serv. Gen. Tech. Rep. WO-24.

Ginrich, S.F. 1967. Measuring and evaluating stocking and stand density in upland hardwood forests in the Central States. For. Sci. 13:38-53.

Guldin J.M. 1991. Uneven-aged BDq regulation of Sierra Nevada mixed conifers. J. For. 89:29-36.

Guldin, J.M., R.M. Farrar, Jr., J.D. Hodges, and J.R. Toliver. 1991. A subjective decision model for classification of uneven-aged silvicultural systems. P. 369-375. in Proceedings of the sixth biennial southern silvicultural research conference. S.S. Coleman and D.G. Neary (comps.). USDA For. Serv. Gen. Tech. Rep. SE-70.

Hannah, P.R. 1987. Regeneration methods for oaks. North. J. Appl. For. 4:97-101.

Heald, R.C. and R. Haight. 1979. A new approach to uneven-aged silviculture and management of mixed conifer-oak forests. California Agric. (May 1979):20-22.

Jackson, L.W.R. 1959. Relation of pine forest overstory opening diameter to growth of pine reproduction. Ecology 40:478-480.

Johnson, P.S. 1977. Predicting oak stump sprouting and sprout development in the Missouri Ozarks. USDA For. Serv. Res. Pap. NC-149.

Johnson, P.S. 1979. Shoot elongation of black oak and white oak sprouts. Can. J. For. Res. 9:489-494.

Johnson, P.S. 1984. Responses of planted northern red oak to three overstory treatments. Can. J. For. Res. 14:536-542.

Johnson, P.S., C.D. Dale, K.R. Davidson and J.R. Law. 1986. Planting northern red oak in the Missouri Ozarks: a prescription. North. J. Appl. For. 3:66-68.

Kormanik, Paul P. 1990. Liquidambar styraciflua L. Sweetgum. P. 400-415 in Silvics of North America: Volume 2. Hardwoods. R.M. Burns and B.H. Honkala (tech. coords.) USDA Agric. Handb. 654.

Law, J.R. and C.G. Lorimer. 1989. Managing uneven-aged stands. P. 6.08(1)-6.08(6) in Central hardwood notes. F.B. Clark (ed.). USDA For. Serv. North Cen. For. Exp. Sta.

Leak, W.B. and S.M. Filip. 1977. Thirty-eight years of group selection in New England northern hardwoods. J. For. 75:641-643.

Loftis, D.L. 1990a. Predicting post-harvest performance of advance red oak reproduction in the southern Appalachians. For. Sci. 36:908-916.

Loftis, D.L. 1990b. A shelterwood method for regenerating red oak in the Southern Appalachians. For. Sci. 36:917-929.

MacKinney, A.L. 1934. Logging damage in selectively logged loblolly pine stands. J. For. 32:92-96.

Marquis, D.M. 1965. Controlling light in small clearcuttings. USDA For. Serv. Res. Pap. NE-39.

Marquis, D.M. 1978. Application of uneven-aged silviculture on public and private lands. P. 25-61 in Combined proceedings on uneven-aged silviculture in the United States. USDA For. Serv. Gen. Tech. Rep. WO-24.

Marquis, D.M. 1989. Alternative silvicultural systems-East. P. 36-45 in Proceedings of the national silviculture workshop: silvicultural challenges and opportunities in the 1990's. USDA For. Serv. Timber Manage.

Marquis, D.M. 1992. Accommodating biological and social issues in hardwood management: the northeast region. P. 111-125 in Proceedings: twentieth annual hardwood symposium of the Hardwood Research Council. National Hardwood Research Council, Memphis, TN.

McDonald, P.M. and G.O. Fiddler. 1991. Vegetation in group selection openings: ecology and manipulation. P. 97-106 in Twelfth annual forest vegetation management conference. Redding, CA.

McQuilkin, R.A. 1975. Growth of four types of white oak reproduction after clearcutting in the Missouri Ozarks. USDA For. Serv. Res. Pap. NC-116.

Minckler, L.S. 1986. My chance: who really understands group selection? J. For. 84: inside back cover.

Minckler, L.S. 1989. Intensive group selection silviculture in central hardwoods after 40 years. P. 35-39 in Proceedings of the seventh central hardwood conference. USDA For. Serv. Gen. Tech. Rep. NC-132.

Minckler, L.S. and J.D. Woerheide. 1965. Reproduction of hardwoods 10 years after cutting as affected by site and opening size. J. For. 63:103-107.

Nyland, R. D. 1987. Selection system and its application to uneven-aged northern hardwoods. P. 49-80 in Managing northern hardwoods; proceedings of a silvicultural proceedings. R. D. Nyland (ed.) Faculty For. Misc. Pub. No. 13. State Univ. of New York, Syracuse, NY.

Pomeroy, K.B. 1949. Loblolly pine seed trees: selection, fruitfulness, and mortality. USDA For. Serv., Southeast. For. Exp. Sta., Sta. Pap. 5.

Potter, M. J. 1988. Tree shelters improve survival and increase early growth. J. For. 86:39-41.

Roach, B.A. 1974. What is selection cutting and how do you make it work: what is group selection and where can it be used. State Univ. New York, AFRI Misc. Rep. No. 5.

Sander, I.L. 1971. Height growth of new oak sprouts depends on size of advance reproduction. J. For. 69:809-811.

Sander, I.L. 1972. Size of oak advance reproduction: key to growth following harvest cutting. USDA For. Serv. Res. Pap. NC-79.

Sander, I.L. 1987. Oak reproduction establishment and early development following shelterwood cutting in Missouri. P. 17-30 in Proceedings fifteenth annual hardwood symposium. Hardwood Res. Council. Memphis, TN.

Sander, I.L. 1988. Guidelines for regenerating Appalachian oak stands. P. 180-198 in Proceedings guidelines for regenerating Appalachian hardwood stands. H.C. Smith, H.C. Perkey, and W.E. Kidd, Jr. (eds.). SAF Publication 88-03. Virginia Univ. Books. Morgantown, WV.

Sander, I.L. and F.B. Clark. 1971. Reproduction of the upland hardwood forests in the Central States. USDA Agric. Handb. 405.

Sander, I.L., C.E. McGee, K.G. Day, and R.E. Willard. 1983. Oak-hickory. P. 116-120 in Silvicultural systems for the major forest types of the United States. R.M. Burns (tech. comp.) Agric. Handb. 445.

Sander, I.L., P.S. Johnson, and R. Rogers. 1984. Evaluating oak advance reproduction in the Missouri Ozarks. USDA For. Serv. Res. Pap. NC-251.

Smith, H.C. 1980. An evaluation of four uneven-age cutting practices in Central Appalachian hardwoods. So. J. Appl. For. 4:193-200.

Smith, H.C. 1981. Diameters of clearcut openings influence Appalachian hardwood stem development--a 10-year study. USDA For. Serv. Res. Pap. NE-476. Smith, D.M. 1986. The practice of silviculture. John Wiley and Sons. New York.

Waldrop, T.A. 1991. Pine-hardwood regeneration in small openings for uneven-aged management. P. 398-408 in Proceedings of the sixth biennial southern silvicultural research conference; S.S. Coleman and D.G. Neary (comps.). USDA For. Serv. Gen. Tech. Rep. SE-70.

Wahlenberg, W.G. 1960. Loblolly pine. Duke Univ. Durham, NC.

Logging Damage to Residual Trees Following Partial Cutting in a Green Ash-Sugarberry Stand in the Mississippi Delta

James S. Meadows[1]

Abstract: Partial cutting in bottomland hardwoods to control stand density and species composition sometimes results in logging damage to the lower bole and/or roots of residual trees. If severe, logging damage may lead to a decline in tree vigor, which may subsequently stimulate the production of epicormic branches, causing a decrease in bole quality and an eventual loss in value of the stand. To investigate this hypothesis, a partial cutting to remove pulpwood-sized trees (i.e., low thinning/improvement cutting) was performed in the summer of 1990 in a 45-year-old green ash-sugarberry stand located adjacent to the Mississippi River in west-central Mississippi. The goal of the thinning operation was to remove small trees of low-value species, particularly sugarberry, and to promote the growth of high-value residual trees, such as green ash. Thinning removed about 40 percent of the trees and 25 percent of the basal area, while increasing average stand diameter by about 12 percent. The partial cutting was also successful in increasing the relative proportion of green ash and decreasing the relative proportions of sugarberry and other species. The logging operation caused widespread damage to the residual stand, with about 62 percent of the residual trees being damaged at least to some extent. Damage to the lower bole and to exposed lateral roots of residual trees were the two most common types of damage. Damage to most trees was minor, but 35 percent of the residual trees experienced at least moderate logging damage. Sugarberry was more commonly damaged than was green ash. Most of the logging damage occurred during the skidding operation. Diameter growth of the residual dominant and codominant green ash averaged 0.39 in. during the first year after thinning. The partial cutting resulted in only a modest increase in the number of epicormic branches per tree, with most of the increases occurring in lower-crown-class trees, already under stress from suppression prior to harvest. Residual green ash and sugarberry trees of the upper crown classes produced very few new epicormic branches during the first year after harvest. These latter data must be considered preliminary in that the possible stimulation of the production of epicormic branches in damaged trees is thought to be a more long-term response to logging damage.

Partial cutting has long been an accepted practice used to control stand density and species composition. However, many managers of hardwood stands have failed to utilize this tool for fear that partial cutting will promote the development of epicormic branches on the boles of residual trees, and thus reduce their value as sawtimber. Bole quality, as manifested by log grade, is an extremely important determinant of the value of hardwood sawtimber. In general, USDA Forest Service log grades 1, 2, and 3 have value ratios of approximately 13:7:1, with butt logs much more likely to be grade 1 than upper logs (Stubbs 1986). Consequently, any silvicultural practice that may potentially result in log grade reduction can lead to a significant loss in value of the residual stand. Epicormic branches are frequent contributors to log grade reduction in partially cut hardwood stands.

---

[1] Silviculturist at the Southern Hardwoods Laboratory, Maintained at Stoneville, Mississippi, by the Southern Forest Experiment Station, Forest Service—USDA, in cooperation with the Mississippi Agricultural and Forestry Experiment Station and the Southern Hardwood Forest Research.

In the past, the popular notion among foresters was that epicormic branches developed on residual trees following partial cutting solely in response to increased sunlight on the bole. However, many researchers have demonstrated that the phenomenon of epicormic branching is not as simple as a direct response to sudden exposure to sunlight. Brown and Kormanik (1970), in an excellent review article, concluded that epicormic branching is a function of several complex factors: (1) stand density, (2) tree vigor, (3) aspect, (4) position on the bole, and (5) genetics. They maintained that, although direct sunlight has a stimulatory effect on the release of suppressed buds, the sudden exposure to direct sunlight serves as a triggering mechanism for the production of epicormic branches' rather than as the direct cause of the phenomenon.

The concept that tree vigor plays a major role in determining the propensity of an individual to produce epicormic branches following partial cutting has been advanced by several researchers (Erdmann et al. 1985, Skilling 1957, Wahlenberg 1950). In each of these studies, trees of the lower crown classes (i.e., low-vigor trees) exhibited a much greater propensity for epicormic branching than did trees of the upper crown classes (i.e., high-vigor trees). These results imply that individual-tree vigor, in combination with genetic differences in resistance to epicormic sprouting among species, acts as the primary controlling mechanism for the production of epicormic branches, while sudden exposure to direct sunlight or some other type of disturbance serves as the primary triggering mechanism for the release of those suppressed buds that eventually develop into epicormic branches. These two factors, individual-tree vigor and sudden exposure to sunlight, interact with each other to control and trigger the phenomenon of epicormic branching.

Partial cutting not only results in the sudden exposure of residual stems to direct sunlight, it may also result in several types and severities of logging damage to those residual trees. Logging damage, particularly in the form of open wounds to the lower bole, has long been considered a serious problem associated with any type of partial cutting. Logging wounds that expose living sapwood may lead to eventual decay and/or discoloration of the wood in the tree. These types of damage not only result in loss of both log grade and log volume, they may also eventually lead to death of the tree. Hesterberg (1957) and Shigo (1966) conducted detailed investigations into the process of decay as a result of logging wounds in northern hardwoods. Hesterberg (1957) concluded that logging scars greater than 4 in. wide or that exposed more than 60-150 sq in. of sapwood were likely to develop decay within 10 years.

The extent of logging damage in partially cut hardwood stands may vary greatly from one stand to another, and depends on: (1) residual basal area, (2) size and maneuverability of equipment, (3) season of logging, (4) level of planning in the logging operation, and (5) skill and pride of equipment operators (Bruhn 1986). In a 60-year-old cherry-maple (*Prunus* L.-*Acer* L.) stand in West Virginia thinned to three different stocking levels, Lamson and others (1984) found that 22-45 percent of the unmarked stems were either destroyed or severely bent over during the logging operation, and that 18-42 percent of the residual standing trees received logging wounds that exposed living sapwood. However, the overall effect on residual stand basal area was slight because 99 percent of the destroyed trees and 55 percent of the wounded trees were less than 5 in. dbh.

Partial cutting, then, may have conflicting consequences, particularly in hardwoods. On one hand, partial cutting generally improves the species composition of the residual stand and promotes increased growth of residual trees. On the other hand, partial cutting may lead to the development of epicormic branches, especially on low-vigor trees, and may result in logging wounds that could eventually develop decay in residual stems. Both of these potential effects may lead to a significant loss in value of the residual stand.

This study addresses the effects of various types and severities of logging damage on tree vigor, epicormic branching, and bole quality of residual trees following a pulpwood thinning in a 45-year-old green ash-sugarberry (*Fraxinus pennsylvanica* Marsh.-*Celtis laevigata* Willd.) stand in the Mississippi Delta. The basic premise is that logging damage to the lower bole and/or lateral roots of residual trees will result in a decline in tree vigor, which will subsequently stimulate the production of epicormic branches, causing a decrease in bole quality and an eventual loss in value of the stand. The objectives of this study were: (1) to determine the effects of pulpwood thinning (i.e., low thinning) on residual stand structure, species composition, and growth; (2) to determine the extent, type, and severity of logging damage to residual stems following pulpwood thinning; and (3) to determine the long-term effects of logging damage on tree vigor, epicormic branching, and bole quality of residual stems following pulpwood thinning.

METHODS

Study Area

The study is located within a geographic area known as Indian Point, along the eastern side of the Mississippi River in southwestern Bolivar County, Mississippi. Indian Point is situated within the batture land between the Mississippi River on the west and the protective levee on the east, and is thus subject to prolonged inundation when the river floods. Most of the tract, including the study site, is owned by Anderson-Tully Company.

The study area consists of approximately 20 acres and is located within a 360-acre, even-aged stand composed primarily of green ash and sugarberry, with scattered large cottonwood (*Populus deltoides* Bartr. ex Marsh.). Stand age was approximately 45 years. The dominant soil type is Tunica clay, underlain at a depth of 2-3 ft by a loamy material. According to information supplied by Anderson-Tully Company, sawtimber volume averaged about 5,200 bd ft/acre (Doyle scale), but some portions of the stand contained as much as 8,500 bd ft of sawtimber per acre. Roughly 50 percent of the sawtimber volume was green ash, 30 percent was sugarberry, and the remaining 20 percent was cottonwood, pecan (*Carya illinoensis* (Wangenh.) K. Koch), and sycamore (*Platanus occidentalis* L.). The current stand developed beneath an original stand of pure black willow (*Salix nigra* Marsh.), which was harvested in 1968, when the green ash and sugarberry trees were pole-sized. Upper-crown-class trees in the current stand were predominantly green ash, whereas lower-crown-class trees were predominantly sugarberry. No cuttings had been made in the stand since 1968.

Plot Installation and Pre-Harvest Measurements

The approximately 20-acre study area is generally rectangular with dimensions of roughly 1,800 ft by 500 ft. Ten permanent sample plots were established systematically across the study area. Two parallel sampling lines, each consisting of five 1/2-acre circular plots, were established, for a sampling intensity of approximately 25 percent. Plots within lines are 400 ft apart; sampling lines are 240 ft apart.

Prior to treatment, species and dbh of each tree on the plot was recorded. After the stand was marked for thinning, but prior to harvest, crown class, total height, merchantable height, length and grade of all sawlogs, and number and location of existing epicormic branches were recorded on those trees designated as "leave" trees.

Thinning Operation

Anderson-Tully Company's objectives for the thinning operation were to increase growth of residual trees, to improve species composition, and to improve stand quality. Marking was performed by Company personnel. The primary marking rule was to remove all merchantable trees not of sawtimber size or quality (with the exception that pole-sized green ash trees someday capable of producing quality sawtimber were not removed). In effect, the thinning operation removed most pulpwood-sized sugarberry, as well as most low-quality sugarberry and green ash sawtimber. In general, the overall goal of the combined low thinning/improvement cutting was to decrease the relative proportion of sugarberry and increase the relative proportion of green ash in the residual stand, and to increase average tree size.

The logging operation was conducted by a private logging crew contracted by Anderson-Tully Company. Rubber-tired skidders were used to remove the merchantable products, in the form of longwood, from the woods. All material cut was marketed as pulpwood.

Post-Harvest Measurements And Logging Damage Assessment

After the logging operation, measurements and observations previously taken on "leave" trees were also taken on those trees marked to be cut, but, for whatever reasons, were not cut.

Logging damage to individual residual trees was assessed on the basis of four factors: (1) type of damage, (2) severity of damage, (3) location of damage, and (4) quadrant where damage occurred. Type of damage was classified as either (1) no damage, (2) root damage, (3) bole damage, (4) crown damage, (5) multiple damages, or (6) completely destroyed. Severity of damage was based on actual measurements of the dimensions of the wound, and was classed as (1) minor (less than 100 sq in. of exposed sapwood), (2) moderate (100-500 sq in.), or (3) severe (greater than 500 sq in.). Location of the damage was recorded as position on the bole: lower, middle, or upper. The quadrant where damage occurred was recorded as one of the four cardinal directions. Measurements of wound size and location, along with notes and observations on wound type and severity, were used to classify logging damage to individual trees according to these four factors.

RESULTS

Stand Structure And Species Composition

One of the primary objectives of the partial cutting operation was to improve stand structure and species composition. This goal was accomplished by reducing stand density, increasing average tree size, and by decreasing the sugarberry component and increasing the green ash component of the residual stand. The effects of the partial cutting on stand structure and species composition are summarized in Table 1.

Prior to harvest, the stand contained nearly 158 trees per acre, with an average basal area of 154 square feet. Average dbh across the stand was 12.1 in. Cutting removed nearly 59 trees per acre, with an average dbh of 10.4 in., representing about 38 square feet of basal area. The logging operation resulted in the destruction of 5 trees per acre, but because average dbh of these destroyed trees was only 5.4 in., the loss in basal area was only 1.0 square feet. After logging, the residual stand contained 94 trees per acre, with an average basal area of nearly 115 square feet. Average dbh of the residual stand was 13.6 in. The logging operation, then, through both cutting and accidental destruction of some small stems, removed about 40 percent of the trees and 25

Table 1.—Stand structure and species composition prior to and immediately following partial cutting in a green ash sugarberry stand in the Mississippi Delta

Stand Condition: Species	**Trees per acre**	**Basal area**	**Average Dbh**
		-ft^2/ac-	-in.-
I. Pre-harvest			
Green ash	19.2	37.8	18.2
Sugarberry	100.2	83.2	11.3
Other species	38.4	33.0	11.3
All trees	157.8	154.0	12.1
II. Cut			
Green ash	1.0	1.6	16.7
Sugarberry	39.0	22.0	9.7
Other species	18.8	14.6	11.3
All trees	58.8	38.2	10.4
III. Destroyed			
Green ash	0.2	0.1	7.4
Sugarberry	3.2	0.6	5.5
Other species	1.6	0.3	4.9
All trees	5.0	1.0	5.4
IV. Post-harvest			
Green ash	18.0	36.1	18.4
Sugarberry	58.0	60.6	12.7
Other species	18.0	18.1	11.7
All trees	94.0	114.8	13.6

percent of the basal area, while increasing average stand diameter by about 12 percent. These data indicate that the goal of improving stand structure was achieved through the partial cutting operation.

The effects of the partial cutting on species composition are also presented in Table 1. Marking of the stand prior to harvest was very successful in discriminating against sugarberry and other low-value species, while favoring green ash. Harvesting removed approximately 42 percent of the sugarberry trees and about 53 percent of the trees of other species. Basal areas were reduced by 27 percent and 45 percent for sugarberry and other species, respectively. In contrast, green ash density was only negligibly reduced by the harvesting operation.

Consequently, the partial cutting was successful in increasing the relative proportion of green ash and in decreasing the relative proportions of sugarberry and other species. Prior to harvest, species composition, in numbers of trees, was 12 percent green ash, 64 percent sugarberry, and 24 percent other species. The residual stand contained 19 percent green ash, 62 percent sugarberry, and 19 percent other species. These figures represent modest but important changes in species composition. Similar trends were found for changes in composition, expressed as a percentage of basal area. Based on basal area, species composition prior to harvest was 25 percent green ash, 54 percent sugarberry, and 21 percent other species. Basal area of the residual stand consisted of 31 percent green ash, 53 percent sugarberry, and 16 percent other species.

The partial cutting had a marked impact on the diameter distribution of each species group and of the stand as a whole (Figure 1). Very few green ash trees were removed, having little effect on residual diameter distribution (Figure 1a). In contrast, sugarberry and the other species were heavily cut, especially in the 8-, 10-, 12-, and 14-inch dbh classes (Figure 1b and 1c). Unfortunately, trees of these low-value species in the 4- and 6-inch classes were generally too small for pulpwood and were not removed from the stand in any great quantity. Overall, the partial cutting changed the diameter distribution from one skewed towards the smaller dbh classes to one more regularly bell-shaped with highest densities in the 14- to 18- inch classes (Figure 1d). Because the majority of the trees in the 4- and 6-inch dbh classes were not removed, the manager will most likely be faced with the same problem in just a few years as these trees move upward into the pulpwood-sized classes.

Logging Damage To Residual Trees

The logging operation caused widespread damage to the residual stand, with about 62 percent of the residual trees being damaged at least to some extent (Table 2). Most of this damage occurred during the skidding operation, as tree-length logs dragged by the skidder scraped against the lower bole and/or exposed lateral roots of residual trees. Much of this damage could have been avoided through more careful skidder operation.

The frequency of logging damage varied somewhat among species groups (Table 2). Sugarberry was the most commonly damaged species, with 66 percent of the residual stems experiencing some degree of logging damage. Damage to green ash trees was less frequent, with approximately 52 percent of the residual stems being damaged. About 60 percent of the residual stems of other species were damaged. Skidder operators apparently utilized greater care when skidding logs near high-value residual green ash trees.

Across all species, there was little variation in the extent of logging damage among all crown classes, except suppressed (Table 2). Trees in the suppressed class were damaged less frequently than trees in the other crown classes. These smaller trees were probably more easily avoided by skidder operators and, therefore, were damaged less frequently. Unfortunately, upper-crown-class sugarberry trees were very commonly damaged during logging, with about 95 percent and 76 percent of the residual dominant and codominant sugarberry trees being damaged, respectively. Most of this damage was in the form of scrapes to the exposed lateral roots of these larger trees.

Table 2.—Extent of logging damage, by species and by crown class, following partial cutting in a green ash sugarberry stand in the Mississippi Delta. All values are in percent of residual trees damaged or destroyed.

Crown class	**Green ash**	**Sugar-berry**	**Other species**	**All trees**
Dominant	50.0	95.0	33.3	66.0
Codominant	54.9	75.8	70.8	69.0
Intermediate	40.0	71.0	66.7	65.2
Suppressed	57.1	51.2	58.5	53.5
All trees	51.6	66.0	60.2	62.2

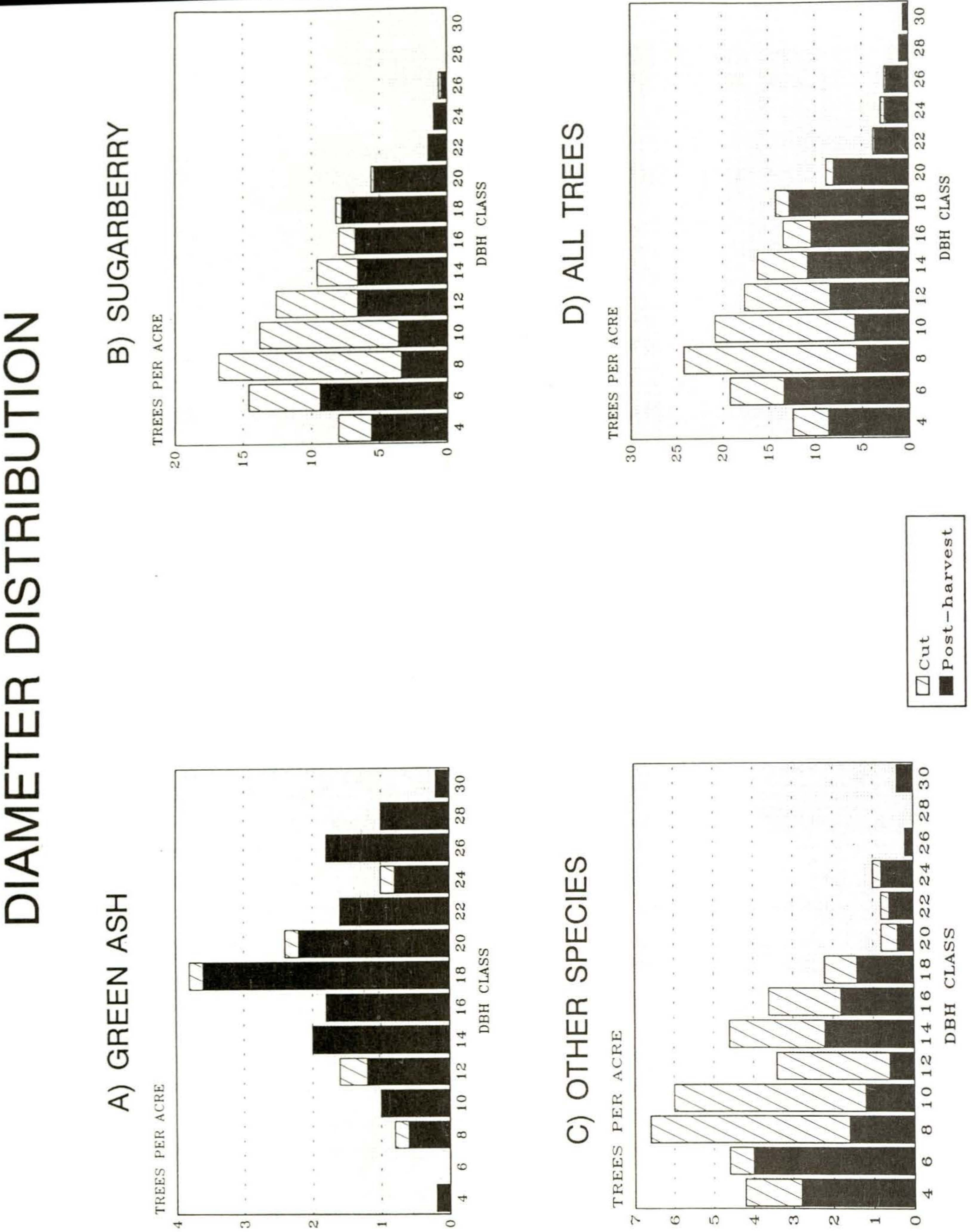


Figure 1.—Diameter distribution prior to and immediately following partial cutting in a green ash-sugarberry stand in the Mississippi Delta: A) green ash, B) sugarberry, C) other species, and D) all trees.

The type of logging damage inflicted on residual trees was classed as either root, bole, crown, multiple, or completely destroyed. The frequency of these various types of logging damage among species groups and among crown classes is summarized in Tables 3 and 4. Across all species and crown classes, damage to the lower bole and to exposed lateral roots of residual trees were the two most common types of damage. Multiple damages, typically a combination of damage to both bole and roots, were also common. Damage to the crowns of residual trees was infrequent because most of the cutting was "from below."

Table 3.—Type of logging damage, by species, following partial cutting in a green ash-sugarberry stand in the Mississippi Delta. All values are in percent.

Type of damage	**Green ash**	**Sugar-berry**	**Other species**	**All trees**
None	48.4	34.0	39.8	37.8
Root	17.5	19.3	16.3	18.4
Bole	18.7	18.9	23.5	19.8
Crown	1.1	2.3	1.0	1.8
Multiple	13.2	20.3	11.2	17.1
Destroyed	1.1	5.2	8.2	5.1
All types	51.6	66.0	60.2	62.2

There was very little variation among species groups in the distribution of these different types of logging damage, with the exception that multiple damages were most common in sugarberry (Table 3). The percentage of trees completely destroyed during logging was also greatest among the lower-value species.

On the other hand, there were differences among crown classes in the distribution of the various types of logging damage (Table 4). Damage to exposed lateral roots was much more common in upper-crown-class trees than in lower-crown-class trees. However, the occurrence of exposed lateral roots is generally more prevalent in large trees. Damage to the lower bole was much less common in dominant trees than in trees of the other crown classes, perhaps because skidder

Table 4.—Type of logging damage, by crown class, following partial cutting in a green ash-sugarberry stand in the Mississippi Delta. All values are in percent.

Type of Damage	**Dom**[1]	**Codom**[1]	**Inter**[1]	**Sup**[1]	**All Trees**
None	34.0	31.0	34.8	46.5	37.8
Root	27.7	30.5	19.1	4.3	18.4
Bole	8.5	18.4	20.2	23.8	19.8
Crown	2.1	0.6	0	3.8	1.8
Multiple	27.7	19.5	22.5	9.7	17.1
Destroyed	0	0	3.4	11.9	5.1
All types	66.0	69.0	65.2	53.5	62.2

[1] Dom - Dominant
Codom = Codominant
Inter = Intermediate
Sup = Suppressed

operators utilized more care when maneuvering around very large trees. The vast majority of trees destroyed during logging were in the suppressed crown class, with no upper-crown-class trees being destroyed. In short, the type of logging damage found in the residual stand was related much more to crown class and size of tree than to species.

The severity of the logging damage to residual trees was classed as either minor, moderate, severe, or completely destroyed, based primarily on the size of the wound. The distribution of these different severities of logging damage among species and among crown classes is summarized in Tables 5 and 6. Across all species and crown classes, damage to most trees was minor, but about 35 percent of the residual trees experienced at least moderate logging damage. Severity of the damage was not generally related to species, except that damage to green ash appeared to be somewhat less severe than damage to sugarberry and other species (about 26 percent of residual green ash trees had at least moderate damage as compared to 37 percent for sugarberry and 36 percent for other species). Severity was also not generally related to crown class, except that all the trees that were completely destroyed were lower-crown-class trees.

Table 5.—Severity of logging damage, by species, following partial cutting in a green ash-sugarberry stand in the Mississippi Delta. All values are in percent.

Severity of damage	**Green ash**	**Sugar-berry**	**Other species**	**All trees**
None	48.4	34.0	39.8	37.8
Minor	25.2	28.8	24.5	27.3
Moderate	19.8	22.6	21.4	21.8
Severe	5.5	9.4	6.1	8.0
Destroyed	1.1	5.2	8.2	5.1
All severities	51.6	66.0	60.2	62.2

Table 6.—Severity of logging damage, by crown class, following partial cutting in a green ash-sugarberry stand in the Mississippi Delta. All values are in percent.

Severity of damage	**Dom**[1]	**Codom**[1]	**Inter**[1]	**Sup**[1]	**All trees**
None	34.0	31.0	34.8	46.5	37.8
Minor	25.6	36.8	30.4	17.3	27.3
Moderate	29.8	27.6	24.7	13.0	21.8
Severe	10.6	4.6	6.7	11.3	8.0
Destroyed	0	0	3.4	11.9	5.1
All severities	66.0	69.0	65.2	53.5	62.2

[1] Dom = Dominant
Codom = Codominant
Inter = Intermediate
Sup = Suppressed

First-Year Diameter Growth

Diameter growth during the first year following partial cutting is summarized by species and by crown class in Table 7. Because growth histories of individual trees are not known and because no uncut plots are available, it is unknown whether these figures represent a significant response to the partial cutting. However, first-year diameter growth of the residual trees is certainly acceptable for these species on this type of site, particularly for the upper-crown-class trees. Dominant and codominant trees of all species averaged 0.33 in. of diameter growth during the first year, with dominant and codominant green ash averaging 0.39 in. and dominant and codominant sugarberry averaging 0.29 in. These figures compare favorably with average diameter growth rates reported by Putnam and others (1960) for dominant and codominant green ash and sugarberry trees on better sites. Particularly impressive is the first-year diameter growth of the dominant trees in the stand, which averaged better than 0.40 in. for all species. Expressed on a 10-year basis, dominant trees of all species are currently growing at the rate of 4.0 in. or better per decade, which is considered to be excellent diameter growth (Putnam et al. 1960).

Table 7.—First-year diameter growth, by species and by crown class, of residual trees following partial cutting in a green ash-sugarberry stand in the Mississippi Delta. All values are in inches.

Crown class	Green ash	Sugar-berry	Other species	All trees
Dominant	0.45	0.40	0.54	0.44
Codominant	0.35	0.26	0.25	0.28
Intermediate	0.18	0.17	0.36	0.20
Suppressed	0.15	0.13	0.15	0.14
All trees	0.35	0.22	0.27	0.25

Epicormic Branching

The effect of partial cutting on epicormic branching of residual trees is summarized by species and by size class in Table 8. Across all species and size classes, the number of epicormic branches per tree increased only slightly, from 0.9 prior to harvesting to 2.2 after one year. The largest increase occurred in trees of other species, which showed an increase of more than 4 branches per tree (from 2.3 to 6.5) during the first year. Green ash and sugarberry, species with little tendency for epicormic branching, showed only modest increases in the number of epicormic branches per tree.

Pulpwood-sized (dbh of 4-12 in.) trees of all species showed a greater propensity to produce epicormic branches than did sawtimber-sized (dbh greater than 12 in.) trees (Table 8). Again, much of this increase was found in trees of other species, principally elms (*Ulmus* L.). Epicormic branching in sawtimber-sized trees increased only slightly during the first year, with increases of less than one branch per tree found in each species. These differences in epicormic branching between size classes agree with the trend reported by Trimble and Seegrist (1973), i.e., that the larger, more vigorous, upper-crown-class trees have less propensity to produce epicormic branches than do the smaller, less vigorous, lower-crown-class trees.

Table 8.—Number of epicormic branches per tree, by species and by size class, prior to and one year following partial cutting in a green ash-sugarberry stand in the Mississippi Delta.

	Pulpwood		**Sawtimber**		**All Trees**	
Species	**Pre**	**Yr 1**	**Pre**	**Yr 1**	**Pre**	**Yr 1**
Green ash	0.3	2.0	0.1	0.9	0.1	1.1
Sugarberry	0.6	1.3	0.6	0.6	0.6	1.1
Other species	2.4	6.8	2.0	2.7	2.3	6.5
All trees	1.2	3.0	0.5	0.8	0.9	2.2

DISCUSSION

Partial cutting in this green ash-sugarberry stand was successful in improving stand structure and species composition, and in creating an environment favorable for increased growth of residual trees. Small, poorly formed individuals of low-value species, such as sugarberry, elm, and boxelder (*Acer negundo* L.), were removed from the stand in an attempt to favor high-value green ash trees. Stand density was reduced and species composition was altered in such a way as to promote the growth and development of desirable residual stems of valuable species. The end result of the partial cutting was to improve the quality and value of the residual stand. From this purely silvicultural perspective, the partial cutting was very successful.

Unfortunately, one of the potential consequences of partial cutting in any stand is logging damage to residual trees. Logging damage following partial cutting in this particular stand was quite extensive, with 62 percent of the residual trees being damaged at least to some extent. Most of the damage was minor, but 35 percent of the residual trees experienced at least moderate logging damage. Obviously, some degree of logging damage must be expected during any partial cutting operation. However, compared to other studies (Lamson et al. 1984), the amount of damage incurred during this study is excessive and much of it could have been avoided through more careful skidder operation.

There is a high probability for the introduction of pathogenic fungi through these logging wounds, an event that would severely reduce the value of the residual stand. Butt rot, the leading cause of cull in southern hardwoods, is very prevalent in stands that have experienced extensive logging damage to residual trees (Toole 1960). Although the rate of rot development within the tree varies with the specific fungus present and with the host tree, Toole (1960) reported average rates of upward spread of butt rot in green ash to be 3.4 ft after 20 years and 5.1 ft after 40 years. Rate of spread in sugarberry was 4.1 ft and 6.1 ft after 20 and 40 years, respectively (Toole 1960). Consequently, trees damaged during this study that do develop butt rot will lose a significant portion of their butt log by the time the stand is ready for final harvest. Because the butt log is the most valuable log in the tree, the effects on final value of the stand could be staggering.

Another possible consequence of logging damage to residual trees is a reduction in tree vigor that could subsequently stimulate the production of epicormic branches. The basic premise in this study is that logging damage may cause a significant loss of vigor in the tree, thus creating a stress that may be severe enough to promote the development of epicormic branches. The end result of this potential phenomenon would be a decrease in bole quality and an eventual loss in value of the stand. Stress-related production of epicormic branches in damaged trees will probably take several years to occur, as the gradual loss of vigor in damaged trees steadily results in an increasingly severe stress.

Consequently, a significant increase in the number of epicormic branches per tree was not expected during the first year, and results indicate that it did not occur. There was only a modest increase in the number of epicormic branches per tree, with most of the increases occurring in lower-crown-class trees. These trees were already under stress from suppression prior to harvest and the sudden exposure of the bole to sunlight following harvest probably triggered the production of epicormic branches on those trees. There was very little change in the number of epicormic branches found on trees of the upper crown classes. Those few upper-crown-class trees that did produce new epicormic branches exhibited slightly lower vigor than did upper-crown-class trees that produced no new epicormic branches. Consequently, these slightly less-vigorous trees were somewhat predisposed to the production of epicormic branches, such that the sudden exposure to direct sunlight following the partial cutting probably triggered the release of those suppressed buds that developed into new epicormic branches.

Partial cutting in this stand had conflicting consequences. On the one hand, it reduced stand density, improved stand structure and species composition, and increased diameter growth of residual trees. On the other hand, partial cutting resulted in extensive logging damage to residual trees. The long-term effects of this damage, in terms of both rot development and stimulation of epicormic branches, are unknown at this time. If these latter effects occur widely throughout the stand over time, the overall effect of the partial cutting on the value of the stand will be negative. However, if the development of rot and the production of epicormic branches are limited in the stand, the overall effect will be positive. Because logging damage in this stand was more widespread than necessary or expected, there is a greater probability of negative effects. However, if the logging operation is properly planned and implemented, damage to residual trees can be minimized and the full silvicultural benefits of partial cutting can be reaped by the manager. In this way, partial cutting can be utilized effectively as a tool to properly manage stands of southern hardwoods.

LITERATURE CITED

Brown, C.L., and P.P. Kormanik. 1970. The influence of stand disturbance on epicormic branching. P. 103-112 in Silviculture and management of southern hardwoods: 19th annual forestry symposium, Hansbrough, T. (ed.). Louisiana State University Press, Baton Rouge.

Bruhn, J.N. 1986. Damage to the residual stand resulting from mechanized thinning of northern hardwoods. P. 74-84 in Hardwood thinning opportunities in the Lake States: Proceedings of a symposium, Sturos, J.A. (comp.). USDA For. Serv. Gen. Tech. Rep. NC-113.

Erdmann, G.G., R.M. Peterson, Jr., and R.R. Oberg. 1985. Crown releasing of red maple poles to shorten high-quality sawlog rotations. Can. J. For. Res. 15:694-700.

Hesterberg, G.A. 1957. Deterioration of sugar maple following logging damage. USDA For. Serv. Lake States For. Exp. Stn., Stn. Pap. 51. 58 p.

Lamson, N.I., H.C. Smith, and G.W. Miller. 1984. Residual stocking not seriously reduced by logging damage from thinning of West Virginia cherry-maple stands. USDA For. Serv. Res. Pap. NE-541. 7 p.

Putnam, J.A., G.M. Furnival, and J.S. McKnight. 1960. Management and inventory of southern hardwoods. USDA Agric. Handb. No. 181. 102 p.

Shigo, A.L. 1966. Decay and discoloration following logging wounds on northern hardwoods. USDA For. Serv. Res. Pap. NE-47. 43 p.

Skilling, D.D. 1957. Is the epicormic branching associated with hardwood pruning wounds influenced by tree crown class? USDA For. Serv. Lake States Exp. Stn., Tech. Notes No. 510. 2 p.

Stubbs, J. 1986. Hardwood epicormic branching—small knots but large losses. South. J. Appl. For. 10:217-220.

Toole, E.R. 1960. Butt rot of southern hardwoods. USDA For. Serv. For. Pest Leaflet 43. 4 p.

Trimble, G.R., Jr., and D.W. Seegrist. 1973. Epicormic branching on hardwood trees bordering forest openings. USDA For. Serv. Res. Pap. NE-261. 6 p.

Wahlenberg, W.G. 1950. Epicormic branching of young yellow-poplar. J. For. 48:417-419.

ACKNOWLEDGMENTS

The author extends his appreciation to Anderson-Tully Company, on whose land this study was installed, for their assistance and cooperation in establishing this research project.

Hardwood Regeneration Twenty Years After Three Distinct Diameter-limit Cuts in Upland Central Hardwoods[1]

Randall B. Heiligmann and Jeffrey S. Ward[2]

Abstract: The effects of diameter-limit cutting on the future species composition and development of 60-80 year-old upland oak stands were studied in southern Ohio. Four treatments, 11-inch diameter-limit cut, 14-inch diameter-limit cut with selective thinning, 14-inch diameter-limit cut with low thinning, and uncut control were evaluated on medium oak sites (black oak site index 60-75 ft) and good oak sites (black oak site index > 75 ft). Twenty 1.8 acre treatment areas were established, 2 complete replications of the 8 treatment combinations and one partial replication. One year after cutting, understory species counts were made for all trees ≤ 3.5 inches dbh on 20 milacre plots within each treatment area. Twenty years after cutting, regeneration ≥ 3.5 inches dbh was tallied on 150x150 foot plots centered in each of the treatment areas. Regeneration 0.6-3.5 inches dbh was inventoried using nine 0.01 acre subplots systematically located within each 150x150 foot plot.

Prior to cutting, oak and hickory accounted for 100 percent of the overstory canopy on medium oak sites, and 82 percent of the overstory canopy on good oak sites. One year after cutting all treatment-site combinations contained large populations of oak-hickory, red maple, and mixed-hardwood regeneration (stems ≤ 3.5 inches dbh), averaging more than 9000 stems per acre. Regeneration density was significantly higher on good than medium site. On good sites, diameter-limit cuts contained almost twice the stem density found on uncut areas. In general, oak-hickory densities were higher on the uncut areas than on the diameter-limit cuts while the densities of mixed hardwoods, red maples, and non-commercial species were higher on the diameter- limit cuts.

Twenty years after diameter-limit cutting regeneration on both medium and good sites was predominantly red maple and mixed-hardwoods. As expected, oak-hickory density was higher on medium than good sites, while mixed-hardwood density was higher on good sites. Red maple was abundant on all diameter-limit cuts on both sites, but was particularly successful on the heavier diameter-limit cuts on medium sites.

Results suggest that heavy diameter-limit cutting on a long cutting cycle may not be an appropriate harvesting method in management situations where maintaining a significant amount of oak in an oak-hickory stand is an important ownership objective. Similarly, heavy diameter limit cuts on long cutting cycles do not appear suitable as "preparatory cuts" for the purpose of stimulating suitable advanced oak regeneration prior to clearcutting.

---

[1] This research was supported in part by the Northeastern Forest Experiment Station, USDA Forest Service and in part by the Mead Corporation.

[2] School of Natural Resources, 2021 Coffey Road, The Ohio State University, Columbus, Ohio 43210. (614) 292-9838; and Department of Forestry and Horticulture, The Connecticut Agricultural Experiment Station, P.O. Box 1106, New Haven, CT 06504. (203) 789-7238

One-third of the 363 million acres of unreserved forest land in the eastern United States and 58 percent of Ohio's commercial forest land is classified as oak-hickory (Waddell et al. 1989, Griffith et al. 1992). Oaks are a highly desirable species component of this region. They are among the most economically valuable species and provide other benefits including important habitat needs for a wide variety of wildlife. Additionally, their fall colors make them an aesthetically desirable component in the landscape.

Obtaining adequate natural oak regeneration following timber harvesting, however, has often proven frustrating. Current knowledge suggests that any form of partial cutting discourages oak regeneration and encourages more tolerant species, such as red maple and other mesophytic hardwood species (Rudolph and Lemmien 1976, Heiligmann et al. 1985, Smith and Miller 1987, Hill and Dickmann 1988). Not infrequently, however, partial cuts involving diameter-limit guidelines have been employed in oak-hickory forests to maximize economic returns from timber sales. Forestry professionals generally regard such partial cuts based on diameter-limit guidelines to be improper for many ownership objectives, though few studies have actually documented long-term effects on stand composition and development (Heiligmann et al. 1985, Smith and Miller 1987).

The objective of this study was to examine the effects of three different diameter-limit cuts on the species composition of non-residual canopy trees and understory regeneration in oak-hickory stands 20 years after harvest and compare that composition with uncut stands. This should provide substantial insight into the possible future species composition of oak-hickory stands subjected to diameter-limit cutting.

METHODS

The study was established by the U.S. Forest Service in 60-65 year-old, even-aged, upland oak stands on the Mead Corporation Experimental Forest in southern Ohio. Topography was flat to locally steep, with slopes up to 50 percent. Predominant soils were Shelocta (fine-loamy, mixed, mesic hapludult), Wharton (fine-loamy, mixed, aquic hapludult), and Latham (clayey, mixed, mesic aquic hapludult) formed from residual shales, sandstones, and siltstones.

The study was established on two site classes - medium sites (black oak site index 60-75 feet at reference age 50 years) and good sites (black oak site index >75 feet at reference age 50 years). The overstory composition of the stands on medium sites prior to treatment (trees ≥ 9.6 inches dbh) was white oak (64 percent), other oaks (28 percent), and hickory (8 percent). The overstory composition of stands on good sites prior to treatment (trees ≥ 9.6 inches dbh) was white oak (60 percent), other oaks (9 percent), hickory (13 percent), yellow poplar (12 percent), and others (6 percent). Other stand characteristics prior to cutting are reported in Table 1. Prior to cutting, red maple was the most common understory species.

Treatments evaluated in this study were as follows:

11-Inch Diameter-Limit Cut - All trees ≥ 11 inches dbh were cut, reducing the cubic foot volume of the stand by one-half. This treatment will be abbreviated 11-DL.

14-Inch Diameter-Limit With Low Thinning - All trees ≥ 14 inches dbh were cut along with most of the trees in the 4-8 inch dbh class in order to reduce the stand cubic foot volume to half. This cutting was an attempt to incorporate a "shelterwood effect" into the diameter-limit cut. This treatment will be abbreviated 14-DL-LT.

14-Inch Diameter-Limit With Selective Thinning - All trees ≥ 14 inches dbh were cut and the density of the remaining stand was thinned to 60 percent stocking (Roach and Gingrich, 1968) favoring the retention of oak. This treatment will be abbreviated 14-DL-SEL.

Uncut - No trees were cut.

Stand characteristics following cutting on good and medium sites are reported in Table 1.

Table 1.—Stand characteristics by site before treatment and by site and treatment 1 year after treatment

Treatment	Density (stem/ac)	Basal area (ft²/ac)	Stocking[a] (%)	DBH (in)
		Conditions Prior To Cut		
Good Sites	188	99	85	9.8
Medium Sites	212	100	89	9.3
		Good Quality Sites After Cutting		
14-DL-LT	59	42	34	11.4
11-DL	126	52	47	8.7
14-DL-SEL	151	68	62	9.1
UNCUT	191	94	82	9.5
		Medium Quality Sites After Cutting		
14-DL-LT	70	41	35	10.3
11-DL	166	58	55	8.0
14-DL-SEL	156	67	60	8.9
UNCUT	202	98	88	9.4

[a] Roach, B. A., and S. F. Gingrich (1968).

A two factor (cutting method, site quality) randomized block experimental design was used. The experiment contained two complete replications of all cutting methods and both site qualities. An additional 14-DL-LT treatment was established on a good site. Three additional 14-DL-SEL treatments were established, two on good sites and one on a medium site. The experiment included 20 treatment areas, each 1.8 acres in size.

The original and residual overstory composition, basal area, and average diameter were determined for each treatment area by complete sampling. Understory species counts by species group were made one year after the cutting for all stems $\leq$ 3.5 inches dbh on 20 milacre plots per treatment area (unpublished data, U.S. Forest Service). Originally, reproduction was categorized by type of reproduction (e.g. seedling, seedling sprout, advanced reproduction, stump sprout), but only one replication of these data on medium sites was saved. Species groups recognized were:

Oak-Hickory: *Quercus alba, Q. coccinea, Q. prinus, Q. rubra, Q. velutina, and Carya spp.*
Red Maple: *Acer rubrum.*
Mixed-Hardwoods: *Acer saccharum, Fagus grandifolia, Fraxinus americana, Juglans nigra, Liriodendron tulipifera, Nyssa sylvatica, Platanus occidentalis, Populus grandidentata, Prunus serotina, Tilia americana, and Ulmus spp.*
Non-Commercial: *Amelanchier spp., Carpinus caroliniana, Castanea dentata, Cercis canadensis, Cornus florida, Hamamelis virginiana, Lindera benzoin, Magnolia acuminata, Malus spp., Oxydendrum arboreum, Pinus echinata, Robinia pseudoacacia, Sassafras albidum, and Tsuga canadensis.*

Twenty years after cutting, tree and stand characteristics were determined within 150x150 foot plots centered in each of the 20 treatment areas. Each plot was surrounded by a 66 foot wide buffer strip which received the same treatment. All trees > 3.5 inches dbh were tallied by species, diameter, crown class, and whether or not the tree had been part of the residual overstory after cutting. Trees 0.6 to 3.5 inches dbh were inventoried by species and crown class using 9 0.01-acre circular subplots systematically located within each 150x150 foot plot. For analysis of 20-year data, all trees not part of the residual overstory were considered reproduction. Thus, reproduction included both advanced reproduction and reproduction which came in following the treatments.

Data were analyzed using analysis of variance with treatment and site quality as factors. Tukey's HSD test was used to test differences among cutting methods. Pearson correlations coefficients were used to evaluate correlations between original and residual stand parameters and regeneration densities 1 year and 20 years after treatment. Differences were judged significant at $p \leq 0.05$.

RESULTS

Regeneration One Year After Treatment

Regeneration density (stems ≤ 3.5 inches dbh) averaged more than 9000 stems per acre on all treatments one year after cutting (Table 2). This high density of regeneration was due to counting all stems ≤ 3.5 inches dbh, rather than those above a certain size threshold (e.g. 4.5 feet in height). Original data identifying the type of regeneration were available for only one replication of the treatments on medium sites. For this replication, first year regeneration on the diameter-limit cuts averaged 56 percent advanced regeneration, 32 percent seedling sprouts, 9 percent seedlings, 1 percent stump sprouts, and 2 percent undetermined. All of the regeneration in the uncut areas was classified as advanced regeneration. While there would be danger in generalizing from these data, the magnitude of the numbers suggest that, at least on the medium sites, advanced regeneration and seedling sprouts accounted for a relatively high proportion of the regeneration, while seedlings and stump sprouts were far less important.

Table 2.—Regeneration density (stems/ac) 1 year after cutting by treatment, species group, and site quality

Treatment	Oak-hickory	Red maple	Mixed-hardwoods	Non-commercial
		Good Quality Sites		
14-DL-LT	7,475	4,300	5,300	4,775
11-DL	2,850	1,700	8,425	7,875
14-DL-SEL	4,550	4,250	4,275	13,175
UNCUT	4,750	2,125	1,575	3,900
		Medium Quality Sites		
14-DL-LT	2,725	1,500	2,625	3,050
11-DL	5,375	2,450	500	2,050
14-DL-SEL	4,350	900	1,550	3,225
UNCUT	7,325	250	375	1,250

Species-group densities of regeneration one year after treatment were not correlated with original or residual stand density, basal area, or stocking. On medium sites there was significantly more red maple on the 11-DL than on the uncut areas. Other species-group densities did not differ significantly among treatments. Diameter-limit cuts, therefore, were pooled to determine if cutting affected regeneration densities relative to the uncut areas.

The effects of diameter-limit cutting on regeneration densities differed by site (Table 2), but all treatment/site combinations contained large populations of oak-hickory, red maple, and mixed-hardwood regeneration from which future canopy trees could develop. On good sites, diameter-limit cuts contained almost twice the stem density found on the uncut areas, 23,017 stems/ac versus 12,350 stems/ac. In contrast, on medium sites there was little difference in stem densities between the diameter-limit cuts and uncut areas, 10,100 stems/ac on the diameter-limit versus 9,200 stems/ac on the uncut. In general, oak-hickory densities were higher on the uncut areas than on the diameter-limit cuts while the densities of mixed-hardwoods, red maples, and non-commercial species were higher on the diameter limit cuts. Oak-hickory accounted for 59 percent of the regeneration on the uncut areas and 32 percent on the diameter-limit cuts.

Regeneration density was significantly higher on good than medium sites, 20,325 stems/ac and 9,875 stems/ac respectively. There were significantly more mixed-hardwood and red maple regeneration on good than on medium sites. Although oak-hickory density was not significantly different between sites, oak-hickory regeneration in the diameter-limit cuts accounted for 42 percent of the regeneration on medium sites compared with 22 percent on good sites.

Non-Residual Canopy Trees Twenty Years After Treatment

Twenty years after harvesting there were distinct differences between sites and treatments in the species composition of trees that had grown into the intermediate, codominant, or dominant crown positions. These trees are referred to hereafter as "non-residual canopy trees".

Uncut areas on good sites averaged 4 non-residual canopy trees per acre (3 red maple, 1 mixed-hardwoods) while diameter-limit cuts on good sites averaged 28 non-residual canopy trees (4 oak-hickory, 14 red maples, 10 mixed-hardwoods). On all diameter-limit cuts on good sites, non-residual canopy red maple and mixed-hardwoods were far more abundant than oak-hickory, with the red maple and mixed-hardwoods accounting for 85 percent of the species composition.

The species composition of non-residual canopy trees on medium sites differed in several ways from that on good sites (Figure 1). First, non-residual canopy trees were 9 times more abundant on uncut medium sites than on uncut good sites (37 versus 4 per acre). Second, oak-hickory constituted a substantially higher proportion (38 to 60 percent) of the non-residual canopy trees on all treatments except the 14-DL-LT. Third, the percent of red maple in the non-residual canopy trees generally increased as the post-treatment residual overstory density decreased. This was particularly evident with the two heaviest cuts, the 11-DL and 14-DL-LT, where red maple constituted 58 and 76 percent of non-residual canopy trees, respectively. Fourth, primarily as a result of the comparatively large number of red maple, the 14-DL-LT averaged more than 3 times non-residual canopy trees per acre as the other treatments, 103 versus 30. And fifth, very few mixed-hardwoods grew into the intermediate or higher crown positions on average sites during the 20 years following treatment.

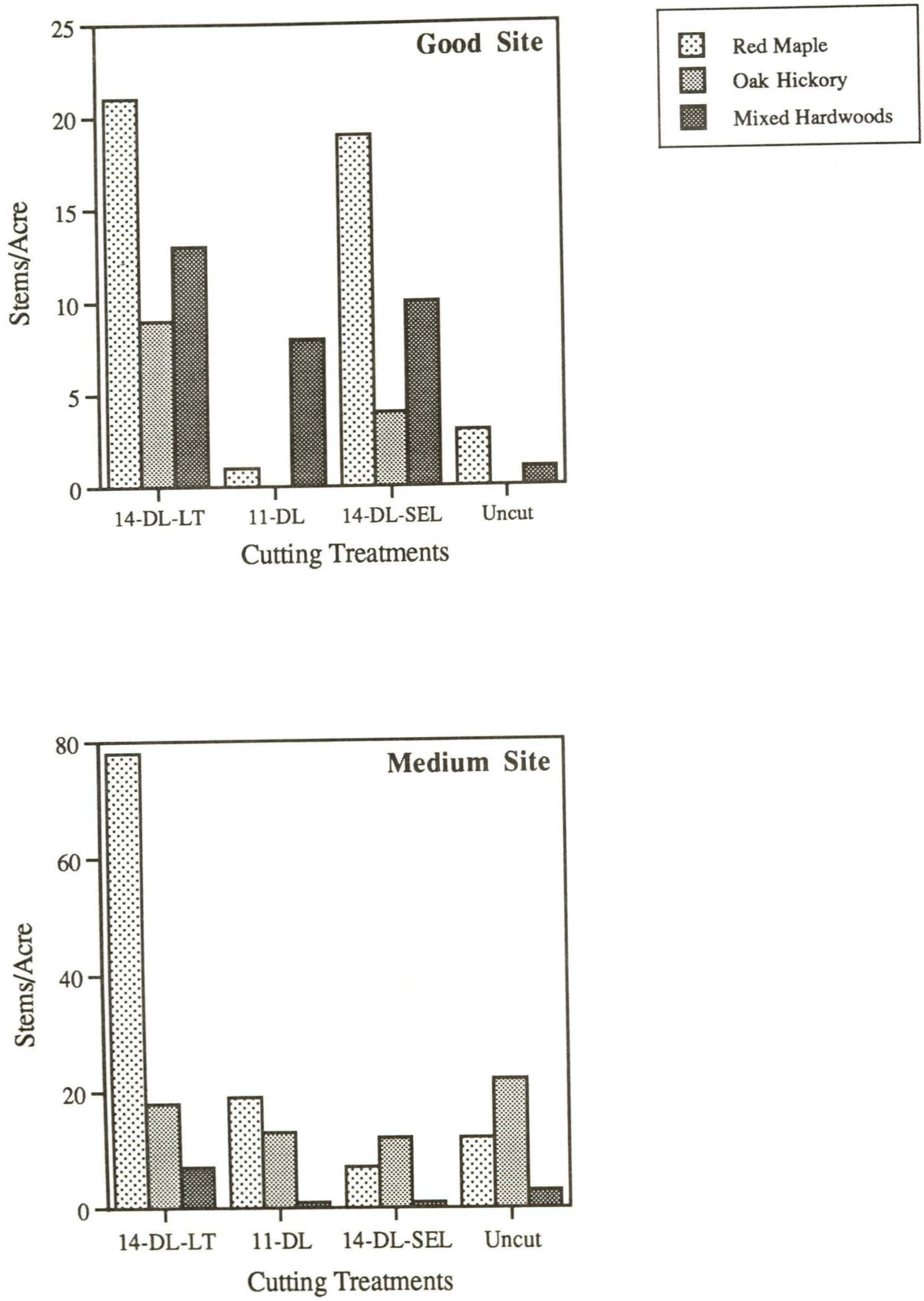


Figure 1.—Density of non-residual canopy trees 20 years after treatment.

Understory Tree Composition Twenty Years After Treatment

As with the non-residual canopy tree composition, there were distinct differences between sites and treatments in understory tree composition. For the most part, these differences paralleled those observed in the non-residual canopy trees.

On good sites, diameter-limit cuts averaged more than 2.5 times as many stems of commercial species per acre as uncut areas (Figure 2). Oak-hickory constituted a relatively small percentage of the understory composition on all treatments. The large increases in numbers of stems per acre observed on the diameter-limit cuts were due almost entirely to increases in the numbers of red maple and mixed-hardwoods. Mixed-hardwoods constituted an important component of the understory composition in the diameter-limit cuts on good sites, accounting for between 26 percent (14-DL-SEL) and 70 percent (11-DL) of the stems of commercial species.

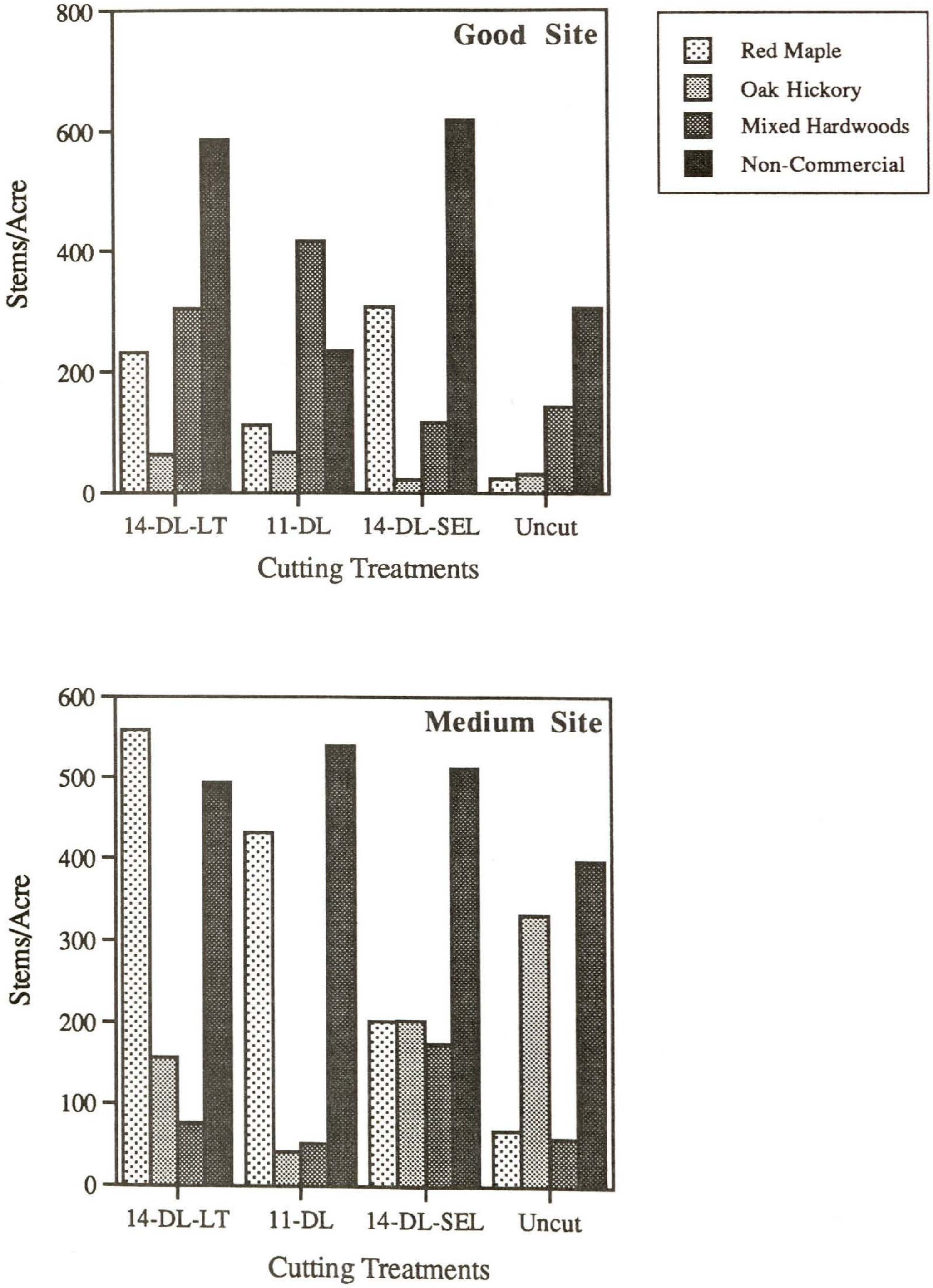


Figure 2.—Understory tree composition 20 years after treatment.

Again, the species composition on medium sites differed in several ways from that on good sites. Unquestionably, the most noticeable characteristic of the understory species composition was the direct relationship between red maple density and post-cut residual basal area. The lower the post-cut basal area, the higher the density of red maple. With the exception of the 11-DL treatment, oak-hickory understory density was much higher on medium sites than on good sites, averaging 150 and 203 stems per acre on the 14-DL-LT and 14-DL-SEL, respectively. Oak-hickory understory was highest, 332 stems per acre, on the uncut areas. In general, mixed-hardwood understory density was much lower on medium sites than on good sites.

DISCUSSION

Diameter-limit cutting in these even-aged upland central hardwood stands increased the amount, proportion, and importance (as expressed by crown position) of red maple and mixed-hardwoods relative to the uncut areas. In the diameter-limit cuts, red maple and mixed-hardwoods were the predominant species moving into the canopy, and were also the most abundant species in the understory.

Diameter-limit cuts, followed by 20 years without additional cutting, appear to have accelerated the succession of the relatively tolerant red maple replacing the less tolerant, slower growing oak-hickory, particularly on the medium sites. On medium sites oak-hickory regeneration fell to 3.6 percent of the first year count, on good sites it fell to 1.1 percent. By comparison, oak percentages on adjacent complete clearcuts were 11.8 percent for the medium sites and 3.9 percent on good sites (Ward and Heiligmann 1990). Partial cutting has been reported to encourage the establishment of more tolerant species in Illinois (Jokela and Sawtelle 1985), West Virginia (Smith and Miller 1987), and Michigan (Abrams and Scott 1989). On good sites, not only did the density of red maple reproduction increase, but also that of the relatively intolerant mixed-hardwoods, particularly yellow poplar. While mixed-hardwood regeneration was present throughout the diameter-limit cuts, it was particularly successful on good sites were the cut had been very heavy and appeared destined to becomepart of the overstory canopy. In diameter-limit cuts, the heavier the cut or the more irregular the distribution of cut trees, the more likely areas within the cut will approach the appearance and characteristics of a commercial or complete clearcut, conditions well suited to the faster growing, predominantly intolerant mixed-hardwoods, and to faster growing tolerants such as red maple. Undoubtedly competition from the greater number of understory stems present on the good site contributed to the significantly lower number of oak present on the good site 20 years later. Johnson and Jacobs (1981) reported that oak reproduction was inhibited by a heavy shrub layer which developed after a shelterwood cut in southwestern Wisconsin. Similarly, Martin and Hix (1988) examined a 26-year-old shelterwood and partly attributed the low proportion of red oak to competition from a high total regeneration density.

Throughout this study oak and hickory have been evaluated as the oak-hickory species group. Unfortunately, the data structure did not allow subdivision of the oak-hickory species group for the understory and non-residual canopy tree classes. For total regeneration (understory + non-residual canopy trees) hickory averaged 62 percent of the oak-hickory species group, oak averaged 38 percent. This percentage distribution probably represents well the understory regeneration which varied from 92 to 99 percent of the total regeneration, depending on the treatment. No assumptions can be made about the proportion of oak and hickory in the non-residual canopy trees. This fact, however, in no way negates the findings. Since the diameter-limit cuts proved relatively ineffective in regenerating the oak-hickory species group as a whole, they most certainly were ineffective in regenerating oak as part of that group.

If oak regeneration is an important management objective in an upland central hardwood stand, it would appear diameter limit cutting with long cutting cycles are not an appropriate harvesting method. Based on this study, such a harvesting strategy would increase the amount of red maple and mixed-hardwoods at the expense of the oak.

Partial cuts are sometimes used in upland central hardwoods in an attempt to stimulate advanced oak regeneration prior to clearcutting. In this study, the understory oak-hickory regeneration 20 years after diameter-limit harvesting averaged 92 stems/ac, 50 stems/acre on good quality sites and 134 stems/acre on medium quality sites. Recommendations suggest adequate advanced oak regeneration be somewhat more than 400 stems of suitable size per acre (Sander 1977). After 20 years, none of the diameter-limit cuts contained that much suitable advanced oak regeneration. The highest understory oak-hickory regeneration, 332 stems/ac, was present in the uncut areas on medium sites. Diameter-limit cuts on medium sites averaged 134 oak-hickory stems/ac. On good sites the uncut areas averaged 31 oak-hickory stems/ac and the diameter-limit cuts averaged 51 oak-hickory stems/ac.

MANAGEMENT IMPLICATIONS

There are unquestionably forest management situations where diameter-limit cutting is an appropriate harvesting method. Such a recommendation, however, requires careful evaluation of short- and long-term forest ownership objectives and individual stand characteristics. The results of this study suggest that if maintaining a significant amount of oak in an oak-hickory stand is an important ownership objective, heavy diameter-limit cutting on a long cutting cycle (20 years) is not an appropriate harvesting method. To the contrary, such a diameter-limit cutting will favor the establishment and growth of red maple and a variety of mostly intolerant mixed-hardwoods that successfully compete in the larger openings created by the harvest. Similarly, heavy diameter-limit cuts on long cutting cycles do not appear suitable as "preparatory cuts" prior to clearcutting for the purpose of stimulating suitable advanced oak regeneration. Such cuts, instead, favor the development of red maple and mixed-hardwood advanced regeneration.

LITERATURE CITED

Abrams, M.D., and M.L. Scott. 1989. Disturbance-mediated accelerated succession in two Michigan forest types. For. Sci. 35: 42-49.

Griffith, Douglas M., DM. DiGiovanni, T.L. Witzel, and E.H. Wharton. 1992. Forest statistics for Ohio, 1991. Northeastern Forest Experiment Station Draft Document.

Heiligmann, R.B., E.R. Norland, and D.E. Hilt. 1985. 28-year-old reproduction on five cutting practices in upland oak. NJAF 2: 17-22.

Hill, J.P., and D.I. Dickmann. 1988. A comparison of three methods for naturally reproducing oak in southern Michigan. NJAF 5: 113-117.

Johnnson, P.S., and R.D. Jacobs. 1981. Northern red oak regeneration after preherbicided clearcutting and shelterwood removal cutting. USDA For. Serv. Res. Pap. NC-202. 5 pp.

Jokela, J.J., and R.A. Sawtelle. 1985. Origin of oak stands on the Springfield Plains; a lesson in oak regeneration. In Proc. Central Hardw. Forest Con. V. pp 181-188.

Martin, A.J., and D.M. Hix. 1988. Regeneration development in an upland hardwood stand following a shelterwood harvest. NJAF 5: 46-49.

Roach, B.A., and S.F. Gingrich. 1968. Even-aged silviculture for upland central hardwoods. USDA Agric. Handb. 355. 39 pp.

Rudolph, V.J. and W.A. Lemmien. 1976. Silvicultural cuttings in an oak-hickory stand in Michigan: 21 year results. In Proc. Central Hardw. Forest Conf. pp 431-453.

Sander, I.L. 1977. A manager's handbook for oaks in the north central states. USDA FS Gen. Tech. Rep. NC-37. 35 pp.

Smith, H.C., and B.W. Miller. 1987. Managing Appalachian hardwood stands using four regeneration practices - 34- year results. NJAF 4: 180-185.

Waddell, K.L., D.D. Oswald, and D.S. Powell. 1989. Forest statistics of the United States, 1987. USDA For. Serv. PNW-RB-168.

Ward, J.S., and R.B. Heiligmann. 1990. Effects of site quality and season of clearcutting on hardwood regeneration in Ohio. NJAF 7: 69-72.

Factors Limiting Northern Red Oak Reproduction in Pennsylvania

Russell S. Walters and L. R. Auchmoody[1]

Abstract: When harvested, upland oak forests of northwestern Pennsylvania generally regenerate to new forests dominated by non-oak species. In 1988, the Northeastern Forest Experiment Station began to identify and learn to manipulate factors that limit the establishment and development of northern red oak (*Quercus rubra* L.) seedlings in second-generation stands on high-quality sites. The study includes three replications located within the Moshanon State Forest and four replications within the Allegheny National Forest on the unglaciated section of the Allegheny Plateau in northwestern Pennsylvania. Each replication includes six plots in which two each were cut to 40 and 60% relative density and two left uncut. One plot of each overstory density level was fenced to exclude deer and one-half of every plot was herbicided to control herbaceous cover and competing hardwoods. The major causes of regeneration failure in oak stands are low numbers and/or small size of oak advance reproduction. The small number of natural red oak seedlings results from infrequent seed crops and destruction of acorns by insects, deer, and small mammals. Deer, small mammals, and insects contribute to slow development and mortality of established seedlings.

INTRODUCTION

The difficulty in regenerating oaks, particularly on the higher quality sites, is widespread throughout all oak forests of eastern North America. Crow and Isebrands (1986) pointed out that this is neither recent nor limited to eastern North America. This problem has been recognized, discussed, and researched for more than 60 years in both the United States and Europe and we still are unable to reproduce oak forests consistently. Moreover, the problem is most acute on higher quality sites where foresters most want to grow oak, especially northern red oak.

Most oak regeneration failures are attributed to the absence of adequate amounts of advance regeneration or the inability of oak to outgrow competitors when released (Sander 1988; Crow 1988). The conditions that led to the establishment of oak types on these better sites are lacking. If natural regeneration is present, natural succession is progressing toward conversion to fast-growing, intolerant, mesic northern hardwood species such as black cherry (*Prunus serotina* Ehrh.), red maple (*Acer rubrum* L.), and sweet birch (*Betula lenta* L.). The problem is intensified in oak stands on the Allegheny Plateau in northwestern Pennsylvania where large populations of white-tailed deer have influenced the development of forest vegetation over a long period (Marquis and Brenneman 1981).

In 1988, the Northeastern Forest Experiment Station began a study in northwestern Pennsylvania to identify the biotic and environmental limitations on the establishment and development of red oak seedlings. This study also will seek to determine how these limitations might be manipulated to encourage red oak in second-generation stands. The effects of deer, rodents, insects, light, competition from herbaceous and woody species, site, stand composition, and acorn availability are some of the factors being evaluated. It is our purpose here to discuss limitations for northern red oak regeneration, especially those encountered in northwestern Pennsylvania, and explain how this study is designed to investigate them. After 4 years, we have gained a considerable understanding of the factors that limit the establishment and early development of red oak seedlings. However, the conclusions presented here are preliminary at this time and further results must await longer term evaluation.

---

[1] Principal Silviculturists, USDA Forest Service, Northeastern Forest Experiment Station, Forestry Sciences Laboratory, P.O. Box 928, Warren, PA 16365.

All replications of this study are located on the unglaciated Allegheny Plateau in northwestern Pennsylvania. We established three replications on the Moshannon State Forest (CLR) in Clearfield County that have completed four growing seasons. In addition, four replications located within the Allegheny National Forest (ANF) have undergone three growing seasons. Two of these ANF replications are in Warren County and two are in Elk County. All study sites are characterized as having good soils and uniform, gentle-rolling topography. They range from 2,000 to 2,300 feet above sea level and are typical of conditions on the Allegheny Plateau. The cool-moist climate is similar at all locations with about 140 frost-free days each year. Rainfall averages about 4 inches per month throughout the growing season and the average growing season temperature is 61°F. Because of ample rainfall, cool temperatures, and much summer cloud cover, soil moisture rarely becomes limiting until late in the growing season. These are excellent growing sites for northern red oak.

Although the soils vary somewhat from replication to replication, they are essentially similar. In general, they are medium textured, moderately well drained, and have 24 to 30 inches of effective rooting depth with good structure and permeability. None of the plots has a soil physical limitation for red oak regeneration, such as severe surface rockiness, shallow depth to bedrock, coarse soil texture, high perched water tables, or excessive slope steepness on south-facing aspects. The forest floor is typically a duff mull, with 2 to 3 inches of litter, a thin fermentation layer, and about 1 inch of humus that grades abruptly into the mineral soil beneath. The plots are equally good for growing oaks as they are for the other associated hardwoods and represent sites that are extremely difficult to regenerate to northern red oak.

All CLR and ANF research sites were located in similar fully stocked stands dominated by northern red oak. These stands were about 80 years old and had no evidence of recent cutting. The CLR stands averaged 137 ft^2 of basal area in 355 trees (1.0 inches dbh and larger)/acre and 13.8 inches dbh. Relative stand density was 87% of the average maximum stocking expected in undisturbed stands of similar size and species composition. Northern red oak made up 55% of the stand basal area with a maximum tree size of 32 inches dbh. White (*Quercus alba* L.), black (*Q. velutina* Lam), and chestnut (*Q. prinus* L.) oaks added 2% more basal area, with red and sugar maples (*Acer saccharum* Marsh.) making up an additional 32%. The other associated overstory species were mainly black cherry, white ash (*Fraxinus americana* L.), American beech (*Fagus grandifolia* Ehrh.), yellow-poplar (*Liriodendron tulipifera* L.), and cucumbertree (*Magnolia acuminata* L.). The ANF stands averaged 139 ft^2 of basal area in 422 trees/acre and 14.5 inches dbh. Relative stand density was 89%. Northern red oak accounted for 49% and white and chestnut oaks 6% of the stand basal area. Red maple and black cherry contributed another 32% to the stand basal area. The balance of the overstory was mostly sugar maple, American beech, yellow-poplar, cucumbertree, and white ash. The largest ANF tree was a 34-inch-dbh red oak.

METHODS

The field layout consists of a randomized complete block split-plot design with six, 4-acre main plots in each replication. The main plot treatments include three levels of residual overstory stand density, with and without fencing. These overstory treatments included two plots each uncut and two plots each cut to 40 and 60% relative density. One plot of each density was then fenced with a

6-strand, high-voltage, electric fence to exclude deer. One-half of each main plot received a broadcast herbicide treatment of 2 lb a.i. glyphosate and 1.5 oz a.i. sulfometuron methyl/acre to control herbaceous cover and competing hardwood species. The other half was not sprayed. All trees on all plots that were smaller than 5.5 inches dbh were cut and the stumps (except for those few oaks cut) treated with 2% Garlon in fuel oil to prevent sprouting. This was done to reduce competition for advance regeneration development from the mid-crown overstory. Each replication then had 12 treatment combinations on 2-acre subplots for a total of 24 acres/replication. Since there are seven replications, the study encompasses 168 acres in total.

Great care was exercised in selecting study sites with fully stocked stands approaching maturity with no recent cutting, at least 15% northern red oak, and no mountain-laurel. We also wanted stands of medium to good site quality (site index of 60 to 75 base age 50), and no site limitations to oak seedling establishment. Within each replication, all six plots were located so as to have uniform topography with similar slope steepness and aspect, soils that were similar, and uniform stand conditions.

Initially, 100% overstory inventories by species and 1-inch dbh classes were completed for each 2-acre subplot. These were used to develop a marking guide for each plot to determine the trees that needed to be retained. Care was taken to closely match the residual stands as to species composition and stand structure on fenced and unfenced plots of each residual density in a replication, and to match the overstory on the herbicided and unherbicided halves of each 4-acre plot. As far as consistent with the above, the objective always was to retain as much red oak as possible in the largest size classes.

These procedures were designed to create basic plots on which we could investigate the process of red oak regeneration rather than merely observing results of practices applied in the forest. In these plots, the limiting factors to the establishment of northern red oak seedlings could be evaluated, manipulated, and made unlimiting. The major limiting factors under investigation and the corrective measures applied are listed in Table 1.

Table 1.—Factors limiting oak regeneration and corrective measures

Limiting factors	**Corrective measure**
Light and other environmental factors limit seedling establishment	Partial overstory removal to vary light and other factors
Deer eat acorns and/or seedlings	Exclude deer with high-voltage electric fences
Understory interference limits seedling	Eliminate understory with herbicide
Acorns not produced by parent stand	Measured and reasons for failure determined
Small mammals consume acorns and/or seedlings	Small mammals excluded on subplots and acorns supplied
Insects destroy acrons and/or seedlings	Insect populations measured and species identified
Forest floor inhibits seedling establishment	Direct seed intact litter, burned and scarified subplots
Other species outcompete oak seedlings	Measured and correlated with light0

EXPERIMENTAL DESIGN

The overall study consists of three main experiments. The first experiment deals with the processes controlling the establishment and development of natural red oak seedlings as affected by acorn supply, manipulation of light by cutting the overstory, elimination of deer browsing by fencing, control of understory interference and competition with herbicide, and insects. This is an intensive investigation to learn the biology of red oak regeneration. The second experiment deals with the impacts of insects and small mammals on acorn predation, seedling establishment, and future seedling development, and how these impacts are affected by intact litter, burning, and soil disturbance in relation to light and competing vegetation. This is a major study that probes the biological factors that may be responsible for the lack of natural oak seedlings and their failure to accumulate as advance regeneration over a wide range of environmental conditions. The third experiment deals with underplanting red oak seedlings as a way of establishing advance regeneration, and also with the insects, large mammals, and small mammals that can affect seedling survival and development. Supplementary experiments deal specifically with determining the important insects that affect acorns while attached to the tree and after they have fallen to the forest floor, causes for the lack of consistent acorn crops, and ways to overcome on-site limitations for seedling establishment, such as the effectiveness of electric fences to exclude deer.

Natural Regeneration Experiment

The natural regeneration experiment evaluates the effects of overstory density, deer browsing, and competition control on the establishment and growth of natural red oak regeneration. Natural regeneration populations are measured annually on 15 permanent, 6-foot-radius plots in each 2-acre treatment plot. On the fenced plots only, individual red oak seedling development as affected by insects and small mammals in relation to light level (overstory density) and competition is further evaluated to learn why red oak advance regeneration does not increase in abundance. Acorn crop size on these plots is estimated annually by cap counts and by direct observations of acorns on the ground in autumn. Causes of acorn crop failure are determined by direct crown observations beginning at time of flowering and continuing through maturation in the following year. Insect populations within the plots are determined each year during peak insect damage periods (to acorns on the ground) by pitfall trapping. The plots also are frequently visited to observe the course of stand development and to determine causal factors governing the direction of stand development.

Direct Seeding Experiment

The direct seeding experiment evaluates the impact of small mammals, insects, light, competition control, litter, and acorn placement on seedling establishment from direct-sown acorns. This experiment is located only in the fenced cutting level plots where deer are excluded. Each herbicided and unherbicided subplot contains two 14-foot by 42-foot installations, one of which is surrounded by a rodent-proof exclosure. Within each installation, acorns were placed on top of the forest floor (0_1 horizon) or 1 inch deep in the mineral soil under three litter treatments: intact forest floor, burning of the forest floor, and scarification (mixing of the forest floor with mineral soil to a depth of 8 inches). Burying acorns at a 1-inch depth simulates the caching of acorns by small mammals and rodents. These treatment combinations provide 72 different treatments.

Red Oak Underplanting Experiment

The red oak underplanting experiment evaluates the impacts of overstory density, deer browsing, and competition control on the survival and development of planted seedlings. Further, red oak seedlings were planted in the herbicided and unherbicided, unfenced plots with tree shelters for protection from deer browsing. Planting represents a way of quickly establishing seedlings in areas that may lack red oak advance regeneration. Tree shelters were developed to protect planted seedlings from deer browsing but also are reported to enhance seedling survival and early height growth (Tuley 1983, 1985). This experiment is designed to determine not only the factors that affect initial survival and development of planted red oak with and without tree shelters, but also those factors that inhibit or may prevent seedlings from attaining dominance in the future stand after final overstory removal. Seedlings are subject to routine annual measurements of height growth and survival, and also are evaluated during the growing season to determine the causes of mortality and/or poor development, particularly from the impact of insects.

Limiting Factors

Limitation to northern red oak seedling establishment can be arranged into three categories: (1) acorn production, (2) acorn predation and desiccation, and (3) seedling predation and competition.

Acorn Production

Of course, for obvious reasons acorns must be produced in order to have seedlings. However, acorn production is notoriously erratic and unpredictable (Sharp and Chisman 1961), varying from species to species, tree to tree, location to location, and year to year (Olson and Boyce 1971). Bumper crops occur irregularly and may be as infrequent as 10 years apart (Downs and McQuiklin 1944). Besides knowing the factors that control acorn production, it is important to learn what happens to those acorns that are produced, what prevents them from developing into seedlings, and what prevents the development of seedlings from acorns that germinate.

Acorn crops were estimated from acorn-cap counts each year from 1988 to 1992 on the CLR plots and from 1990 to 1992 on the ANF plots. Caps were counted on 30 systematically located 1 ft^2 plots in each fenced 4-acre plot. The annual per acre acorn crop for the CLR plots averaged 104, 105, 129 and 25 thousand for each plot from 1988 to 1991, respectively. The ANF plots averaged 46 and 58 thousand per acre, respectively, for 1990 and 1991. There were no acorns produced on any plot in either location in 1992.

Acorns develop only from fertilized flowers, never from unfertilized flowers by asexual means. Oaks have imperfect flowers and are monoecious. Staminate and pistillate flowers are borne separately on the same tree and depend on wind for dissemination of pollen. Oaks produce abundant staminate flowers nearly every year, but the number of pistillate flowers may vary greatly from year to year. The causes of cyclic flower production are not fully understood, but weather and genetics often are implicated (Sharp and Chisman 1961; Sharp and Sprague 1967; Olson and Boyce 1971). Thus, a lack of pistallate flowers may contribute to poor acorn production in some years, though flower abortion also is high in most years (McQuilken 1983). Unfavorable weather conditions at the time of pollination during flower development are among the probable causes; wind, late frost, prolonged rain, relative humidity, and temperature have been shown to influence pollination (Sharp and Chisman 1961). Unfertilized pistillate flowers abort, and oak flowers occasionally are killed by late spring frosts (Sharp and Sprague 1967). We observed a freeze that killed the entire crop of staminate flowers in May 1991 and resulted in the total acorn crop failure in 1992 reported above. Since similar freezes and hard frosts in late spring are common on the Allegheny Plateau, this is likely an important limitation to acorn production for the region.

Insects are another likely cause of oak flower abortion and hence reduced acorn production. In a Missouri study, rapid flower abortion and abscission was observed in May and early June, which corresponded with the time of pollen shed and pollination. But the abortion also may have been related to the feeding behavior of treehoppers, which are sucking insects of the family *Membracidae*. Adult treehoppers were observed with their stylets inserted into the stigmas of oak pistillate flowers. The flowers turned from green to brown within a week and aborted (Cecich et al. 1991). Apparently, the treehopper can pierce the female flower, causing physical damage, or perhaps inhibiting salivary compounds are injected that promote abortion. We have not observed this damage in northwestern Pennsylvania, but neither have we looked for it. Such damage is extremely difficult to see without physically being in the tree canopy at frequent intervals.

Finally, acorn production within a stand may be limited simply because there are only a few oaks available that produce seed. Not all trees produce acorns and some are consistently poor acorn producers. Some have few to none, even in good mast years, while others produce small or no acorn crops because of their small crown size, subordinate crown position, or poor health (Downs and McQuilkin 1944; Sharp and Sprague 1967). If acorn production is a management goal, whether for mast production or seed source, it is important to select "leave trees" in the thinnings or other partial cuttings that are good acorn producers.

Even when acorns are produced, there are still many damaging agents that destroy them or can prevent their germination. The *Curculio* weevil attacks maturing acorns while they are still attached to the trees. After dropping to the forest floor, acorns are prize food for many animals and birds including white-tailed deer, chipmunks, squirrels, mice, turkeys, and blue jays (Downs and McQuilkin 1944; Gysel 1957; Marquis et al. 1976; Darley-Hill and Johnson 1981; Galford et al. 1988, 1991). If not eaten, exposed acorns not covered by forest litter can quickly desiccate. Acorns also are targets for insects and other arthropods that live in the forest floor.

Curculio weevils probably are the best known "worms" that attack acorns. Each year they destroy about half of the acorn crop (Galford et al. 1988). Arend and Scholz (1969) found that *Curculio* larvae infected up to 90% of the fallen acorns. The adult females bore a hole in the immature acorn pericarp (shell) while it is still attached to the tree and oviposit inside. The eggs hatch and the larvae feed on the acorn cotyledons. After abscission, when the acorn is on the ground, the larvae emerge by chewing a characteristic hole in the pericarp. The larvae overwinter in the soil and pupate in the spring or early summer. The adults then emerge from the soil and mate, and the female deposits eggs in the new acorns developing on the trees, completing the life cycle (Gibson 1982; McQuilkin 1983). Not all acorns infected with *Curculio* weevils are destroyed. However, seedlings resulting from "weeviled" acorns often are less vigorous and may have poor survival because some of the cotyledonary reserve has been consumed. In a collection of 536 acorns from the 1989 bumper crop, about 25% were infected with *Curculio* weevils. Of the infected acorns, 53% germinated and produced seedlings. About 12% of that 1989 bumper crop was destroyed while still on the trees.

Acorn Predation

Upon falling to the ground, acorns are subject to intense predation by several species of gound insects and millipedes. Two important species that damage germinating acorns were caught in pitfall traps in 1989 and 1990: the weevil *Conotrachalus posticatus* Boheman and the nitidulid or sap beetle *Stelidata octomaculata* Say. Acorn samples collected near the pitfall traps revealed that the radicle tips of 50% of the acorns had been eaten by larvae of the acorn moth *Valentinia glandulella* Riley, and that 60% of the acorns were infested with moth larvae. Although previously not considered a major problem, the acorn moth now must be considered a major pest of germinating acorns in Pennsylvania (Galford 1986a; Galford et al. 1991). Millipedes are another previously unreported pest of germinating acorns. Up to 17% of the acorn radicles in areas with heavy acorn crops were damaged in 1991 by millipedes (Galford et al. 1992).

In a companion study, acorns were sown on the forest floor surface and buried both under wire cages (rodent protected) and outside wire boxes. Rodents destroyed virtually every acorn outside of the boxes so that insect activity could not be evaluated. However, for those acorns under the wire boxes, insects destroyed 92% of the acorns on the surface but only 8% of those that were buried. Of 1,800 acorns surface sown under hardware cloth boxes, desiccation destroyed 30% and mice pilferred another 7%. Thus, 1,139 (63%) of the acorns germinated but only 152 (13%) of those germinating survived insect destruction and grew into seedlings. The insect damage was primarily by the acorn moth and the *Conotrachelus* weevil. Most of the newly rooted seedlings were killed due to heavy weevil feeding on the radicles and shoots. On some seedlings, sap beetles ate the tender top shoots, destroying any chance for the acorn to resprout. Acorn placement and rodent protection did result in significant differences in seedling number, acorns taken by rodents, and acorn destroyed by insects. There were no differences due to overstory density or herbicide treatment (Galford et al. 1991).

As mentioned previously, acorns on the ground are heavily predated by a variety of mammals and birds. Arboreal-feeding birds and squirrels reportedly consume as much as 25% of any mature acorn crop (Downs and McQuilkin 1944; Gysel 1957). Our own observations confirm that white-tailed deer are major consumers of acorns. In nothwestern Pennsylvania, deer are plentiful with county populations estimated to range from 21 to 32/mi^2. This is an average of eight animals/mi^2 over the winter carrying-capacity goal as determined by the Pennsylvania Game Commission.[2] This large deer population consumes many acorns. Gray squirrels are less important as acorn predators than chipmunks and mice simply because there are fewer squirrels. In most years, intense predation by birds, mammals, and insects destroy nearly all of the acorn crop, especially in years when the mast croop is poor to average. Two years after treatment, there were an average of more than 700 northern red oak seedlings per acre on the CLR fenced plots and less than 300 on the unfenced plots. Although it is not possible to distinguish between acorn and seedling consumption by deer, the net difference between the fenced and unfenced number does suggest the deer impact on oak seedling density.

Acorn predators such as chipmunks, mice, squirrels, and blue jays also disperse acorns. These animals transport acorns, often over considerable distances, to caching sites and bury ("plant") them. These buried acorns are protected from deer, other small mammals and insects, and from dessication. Many cached acorns are subsequently retrieved and consumed, but many are not. Since cached acorns generally are in locations favorable for germination, unretrieved acorns often germinate and produce seedlings. Most new oak seedlings become established only in years of good to bumper acorn crops (Olson and Boyce 1971; Watt 1979); these are years when many more acorns are cached than are retrieved. Janzen (1971) recognized predation as the necessary "cost" to the plant of the essential benefit--dispersal/planting--of acorns provided by these animals.

Seedling Predation and Competition

In those infrequent years of bumper seed crops, some acorns may escape damage and germinate, but even abundant germination does not ensure adequate stocking of oak seedlings. Any new seedlings must survive deer browsing, clipping by small mammals, insect attack, low light, and usually a combination of these. If they survive, the oak seedlings still must compete with faster growing associated hardwood regeneration. The contrast in the number of red oak seedlings per acre reported above for the fenced and unfenced CLR plots suggests the impact that deer exert on oak regeneration.

When white-tailed deer populations exceed levels above 18/mi^2 in the deciduous forests on the Allegheny Plateau, species richness and abundance of herbaceous and woody vegetation decline.[3]

---

[2] Unpublished data, William Palmer, Pennsylvania Game Commission, 1992.

[3] Personal communication, David S. deCalesta, Northeastern Forest Experiment Station, Warren, PA, 1992.

Large deer herds have influenced forest vegetation development in northwestern Pennsylvania over a long period. As a result, understory vegetation is sparse in most uncut stands and new seedlings are severely browsed, causing shifts in species composition or reduced stocking. Most understories are dominated by hayscented fern (*Dennstaedia punctilobula* (Michx.) Moore), striped maple (*Acer pensylvanicum* L.), American beech root suckers or if tree seedlings are present, by black cherry, red maple, or sweet birch (Marquis et al. 1976; Marquis and Brenneman 1981). There are few if any oak and those few do not respond vigorously enough to compete.

The total impact of insect damage on the survival and growth of understory oak seedlings is largely unknown. Insect outbreaks occasionally cause visible mortality, but damage is usually moderate, subtle, and cummulative. Many seedlings simply fail to leaf out in the spring after a couple of years of insect damage. From the 1,800 acorns surface sown under hardware cloth boxes, 422 seedlings became established initially, but 64% of these were subsequently destroyed by insects. Most of these new seedlings were killed due to heavy *Conotrachelus* weevil feeding on the radicles and shoots. Some damage was attributed to nitidulid or sap beetles in concert with the weevils (Galford et al. 1991). Another weevil, *Barypeithes pellucidus* Boheman, was found to be a pest of new seedlings by girdling the stems (Galford 1986b, 1987). In Ohio, more than 20% of the new oak seedlings were topkilled at least once by this weevil (Galford et al. 1988).

In addition to eating acorns, rodents also feed on new seedlings. From a group of new oak seedlings, we observed that rodents had chewed the tops off of 66% (Galford et al. 1991). In other areas, more than 80% of the new seedlings had been chewed off one or more times (Galford et al. 1988); many of these shoots are consumed. Acorn germination is hypogeal, that is, the cotyledons remain in place attached at the base of the new seedling stem. We believe that at least some new seedlings are destroyed by rodents retrieving the residual cotyledon.

Despite these factors that limit acorn production and oak seedling establishment, acorns do germinate and some new oak seedlings become established. However, few of these survive more than a year or two. Surviving stems remain small, generally less than 1 foot tall. Dieback is to ground level and resprouting is frequent. Surviving stems grow more slowly and are unable to respond as vigorously to attack as non-oak understory components. Dieback and mortality generally has been attributed to too little light and inadequate moisture (Korstian 1927; Merz and Boyce 1956; Olson and Boyce 1971; McQuilkin 1975). On the Allegheny Plateau, there are few northern red oak seedlings and these are small and slow growing. They do not do well in competition with other hardwoods such as black cherry, red maple, white ash, and sweet birch. And few will gain dominance in the emerging second-generation stands. The fenced CLR plots averaged 7,200 seedlings/acre of commercial species 2 years after treatment. Of these, 26% were taller than 1 foot. In contrast, the unfenced plots averaged 5,100 seedlings/acre and 12% were taller than 1 foot. Red maple was the most abundant species followed by black cherry. As reported above, these plots had about 700 and 300 red oak seedlings/acre in the fenced and unfenced plots, respectively, with about 1% and 0.1% of them taller than 1 foot.

SUMMARY

Harvested upland oak forests of northwestern Pennsylvania generally regenerate to new forests dominated by non-oak species such as black cherry, red maple, and sweet birch. The major causes of regeneration failures in oak stands are low numbers, low vigor, and/or small size of oak advance reproduction. Natural regeneration of northern red oak is limited by infrequent acorn crops and the destruction of large numbers of acorns by animals (white-tailed deer, chipmunks, mice, and birds) and insects, and by desiccation. Deer browsing, small mammals, insects, low light, competition from other fast-growing hardwoods, and usually a combination effect from several of these contribute to slow development and mortality of established oak seedlings. These conclusions are based on 3 years of observation of the ANF plots and 4 years of the CLR plots, respectively. Final conclusions await longer term evaluations.

LITERATURE CITED

Arend, J.L., and H.T. Scholz. 1969. Oak forests of the Lake States and their management. USDA For. Serv. Res. Pap. NC-31.

Cecich, R.A., G.L. Brown, and B.K. Piotter. 1991. Pistillate flower abortion in three species of oak. P. 578 in McCormick, L.H., and K.W. Gottschalk (eds.). Proc., 8th central hardwood forest conf. March 3-6, 1991, Pennsylvania State Univ., University Park.

Crow, T.R. 1988. Reproduction mode and mechanisms for self-replacement of northern red oak (*Quercus rubra*)--a review. For. Sci. 34: 19-40.

Crow, T.R., and J.G. Isebrands. 1986. Oak regeneration - an update. P. 73-86 in Proc., integrated pest management symposium for northern forests. Univ. Wisconsin Coop. Ext. Serv., Madison.

Darley-Hill, S., and W.C. Johnson. 1981. Acorn dispersal by the blue jay (*Cyanocitta cristata*). Oecologia 50: 231-232.

Downs, A.A., and W.E. McQuilkin. 1944. Seed production of southern Appalachian oaks. J. For. 42: 913-920.

Galford, J.R. 1986a. Primary infestation of sprouting chestnut, red and white oak acorns by *Valentinia glandulella* (Lepidoptera:Blastobasidae). Entomol. News 97: 109-112.

Galford, J.R. 1986b. The weevil *Barypeithes pellucidus* (Coleoptera: Curculionidae) feeds on northern red oak, *Quercus rubra* seedlings. Entomol. News 97: 113-114.

Galford, J.R. 1987. Feeding habits of the weevil *Barypeithes pellucidus* (Coleoptera:Curculionidae). Entomol. News 98: 163-164.

Galford, J.R., J.W. Peacock, and S.L. Wright. 1988. Insects and other pests affecting oak regeneration. P. 219-225 in Smith, H.C., A.W. Perkey, and W.E. Kidd, Jr. (eds.). Proc., guidelines for regenerating Appalachian hardwood stands. May 24-26, 1988, West Virginia Univ., Morgantown. Soc. Am. For. Publ. 88-03.

Galford, J., L.R. Auchmoody, H.C. Smith, and R.S. Walters. 1991. Insects affecting establishment of northern red oak seedlings in central Pennsylvania. P. 271-280 in McCormick, L.H., and K.W. Gottschalk (eds.). Proc., 8th central hardwood forest conf. March 3-6, 1991, Pennsylvania State Univ., University Park.

Galford, J.R., L.R. Auchmoody, R.S. Walters, and H.C. Smith. 1992. Millipede damage to germinating acorns of northern red oak. USDA For. Serv. Res. Pap. NE-667.

Gibson, L.P. 1982. Insects that damage northern red oak acorns. USDA For. Serv. Res. Pap. NE-492.

Gysel, L.W. 1957. Acorn production on good, medium, and poor oak sites in southern Michigan. J. For. 55: 570-574.

Janzen, D.H. 1971. Seed predation by animals. Ann. Rev. Ecol. Syst. 2: 465-492.

Korstian, C.F. 1927. Factors controlling germination and early survival in oaks. Yale Univ. Sch. of For. Bull. 19.

Marquis, D.A., and R. Brenneman. 1981. The impact of deer on forest vegetation in Pennsylvania. USDA For. Serv. Gen. Tech. Rep. NE-65.

Marquis, D.A., P.L. Eckert, and B.A. Roach. 1976. Acorn weevils, rodents, and deer all contribute to oak regeneration difficulties in Pennsylvania. USDA For. Serv. Res. Pap. NE-356.

McQuilkin, R.A. 1975. Growth of four types of white oak reproduction after clearcutting in the Missouri Ozarks. USDA For. Serv. Res. Pap. NC-116.

McQuilkin, R.A. 1983. Silvical factors affecting the regeneration of oaks and associated species in Pennsylvania. P. 37-65 in Proc. 1983 Penn State forestry issues conf. March 15-16, 1983, Pennsylvania State Univ., University Park.

Merz, R.W., and S.G. Boyce. 1956. Age of oak seedlings. J. For. 54: 774-775.

Olson, D.F., Jr., and S.G. Boyce. 1971. Factors affecting acorn production and germination and early growth of seedlings and seedling sprouts. P. 44-48 in Oak Symp. Proc. August 16-20, 1971, Morgantown. USDA For. Serv., Northeast. For. Exp. Stn., Upper Darby, PA.

Sander, I.L. 1988. Guidelines for regeneration Appalachian oak stands. P. 189-198 in Smith, H.C., A.W. Perkey, and W.E. Kidd, Jr. (eds.). Proc., guidelines for regenerating Appalachian hardwood stands, May 24-26, 1988, West Virginia Univ., Morgantown. Soc. Am. For. Publ. 88-03.

Sharp, W.M., and H.H. Chisman. 1961. Flowering and fruiting in the white oaks. I. Staminate flowering through pollen dispersal. Ecology 42: 365-372.

Shart, W.M., and V.G. Spraque. 1967. Flowering and fruiting in the white oaks. Pistillate flowering, acorn development, weather, and yields. Ecology 48: 243-251.

Tuley, G. 1983. Shelters improve the growth of young trees in the forest. Q. J. For. 77: 77-87.

Tuley, G. 1985. The growth of young oak trees in shelters. Forestry 58: 181-195.

Watt, R.F. 1979. The need for adequate advance regeneration in oak stands. P. 11-17 in Holt, H.A., B. C. Fischer (eds.). Proc., regenerating oaks in upland hardwood forests. Purdue Univ. Res. Found., West Lafayette, IN.

Vegetation of Loess Bluff Ravines in the Jackson Purchase Region of Kentucky

William S. Bryant[1]

Abstract: Forest vegetation of some loess bluff ravines in the Jackson Purchase Region of Kentucky was sampled. A total of 27 tree species comprised the mixed mesophytic association with *Acer saccharum*, *Fagus grandifolia* and *Liquidambar styraciflua* as the dominants. This assemblage of species agrees with that reported for the loess bluffs over 100 years ago. Basal area averaged 27.2 m^2/ha; density 289.5 trees/ha; and diversity (H') ranged from 3.01-3.52. Species similarity was stronger between the forests of the loess bluffs and those of the Appalachians, but especially the dissected Illinoian till plains, than to adjacent communities on thin loess. Disjuncts from Braun's Mixed Mesophytic Forest Region, *Tilia heterophylla* and *Magnolia acuminata*, and the composition of loess bluff forests relative to other forests in the Jackson Purchase tend to support the refugial nature of the loess bluff ravines.

INTRODUCTION

The forests of the loess bluffs of the Jackson Purchase Region of Kentucky were first given attention over 100 years ago (DeFriese 1880, 1884, Loughridge 1888). Those writers described the bluff forests as "some of the most variable of the original forest growth" and their lists of tree species pointed to a vegetational and floristic distinctiveness unlike other sections of the Jackson Purchase. According to the 1820 General Land Office Survey, the vegetation of the Jackson Purchase was a mixture of oak-hickory (Bryant and Martin 1988) and extensive barrens (Dicken 1935). Exceptions included bottomland hardwoods (Bryant 1990), swamps, and forests of the loess bluffs. It was because of mixed mesophytic forest communities of the bluffs that Braun (1950) included the Jackson Purchase in her Western Mesophytic Forest Region rather than Oak-Hickory.

The loess bluffs of the Jackson Purchase are the northern extension of a long belt of silty upland soils along the east side of the Mississippi River bottoms that run from southwestern Kentucky to Louisiana (Bennett 1921). Crowley's Ridge is a cut-off outlier of these bluffs, but on the west side of the river in Missouri and Arkansas (Bennett 1921, Braun 1950).

Loughridge (1888) recognized the vegetational similarities between the bluff forests of Kentucky and those in Tennessee, Mississippi, and Louisiana. Braun (1950) noted the gradual change in vegetational composition of the bluffs along the length of their N-S gradient with northern species dropping out and southern species entering. A unifying characteristic was the occurrence of cane, *Arundinaria gigantea*, throughout the length of the bluffs. Its presence led to the name "cane hills" for various portions of the bluffs (Loughridge 1888, Davis 1923). Because of grazing and other disturbances, cane has virtually disappeared from the uplands (Shull 1921, Heineke 1987) and few intact forest remnants exist.

---

[1] Professor, Thomas More College, Crestview Hills, Kentucky 41017.

Recent floristic surveys of the loess bluffs in Kentucky (Wilson 1976, Bryan 1977, Grubbs and Fuller 1991) have shown the flora to be distinct from adjacent areas, however contemporary vegetational studies are lacking. To the south, in Tennessee (Braun 1950, Miller and Neiswender 1987a, b, 1989, Miller and Holyfield 1986); in Mississippi (Caplenor 1968); in Louisiana (Brown 1972, Delcourt and Delcourt 1974, 1975); and on Crowley's Ridge (Clark 1977) there have been more detailed vegetational studies.

The purpose of this study was to determine the structure and composition of the vegetation for the least disturbed ravines of the Kentucky loess bluffs; to compare these to other forest communities in the Jackson Purchase and elsewhere; and to assess the biogeographical significance (Braun 1950, Delcourt and Delcourt 1974) of these bluff ravines.

THE ENVIRONMENT

The loess bluffs, from 30-60 meters in height, arise abruptly along the eastern side of the Mississippi River floodplain in Ballard, Carlisle, Hickman and Fulton Counties (Davis 1923). Except for dissection by Mayfield Creek, Bayou deChien and Obion Creek, the bluffs are contiguous in western Kentucky (Figure 1). The loess deposits are of Pleistocene origin and cover Tertiary and Cretaceous sands and gravels (McFarland 1943). Numerous ravines, known locally as "gulfs", form trenches throughout (Davis 1923). The loess is deepest near the Mississippi River and thins to the east.

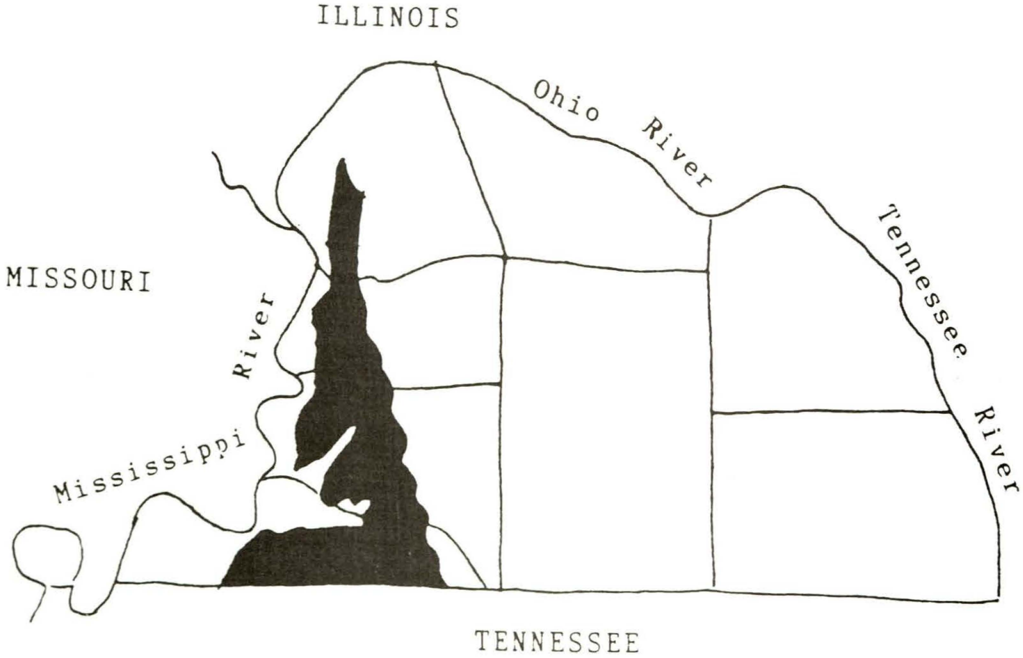


Figure 1.—The location of the loess bluffs (blackened area) in the 8 county Jackson Purchase Region of Kentucky (after Davis 1923).

Memphis silt loan is the primary soil type on the deep loess (Soil Conservation Service, unpub.). This soil is typical of areas of steep relief and tends to have a deep water table. The loess is highly fertile calcareous silt and because of this much of the land adjacent to the bluffs has been converted to agriculture (Grubbs and Fuller 1991). Throughout the 4 counties, erosion has removed several meters of loess on steep side slopes uncovering previously buried coastal plain sediments (Soil Conservation Service, unpub.).

The climate of the Jackson Purchase Region is humid and temperate. The average annual precipitation is 132 cm and the mean annual temperature is 14 c (Newton and Sims 1987).

METHODS

Vegetation of selected loess bluff ravines was sampled as one part of a broader study of the Jackson Purchase vegetation. Visits were made to potential study sites in each of the 4 counties in the cane hills section of the Purchase (Davis 1923). Two sites, one in Carlisle and one in Fulton Counties, that had been floristically studied by Bryan (1977) were selected for the most intensive sampling. Two other sites, one in Ballard and another in Fulton County, were quantitatively sampled. Stands varied from 3-5 ha in size (Bryan 1977).

Vegetation was sampled in 0.04 ha circular plots, randomly spaced throughout each stand. Over 20% of the 198 plots taken in the 4 counties were from little disturbed forests on the bluffs. All woody individuals $\geq$10 cm dbh were measured in each plot. Tree data were analyzed to relative frequency (RF), relative density (RD), and relative dominance (RDo). These values were summed to give an importance value (IV) for each species. Density (trees/ha), basal area (m^2/ha), and species diversity (H') (Magurran 1988) were calculated. Coefficient of similarity follows Bray and Curtis (1957).

Notes on seedlings, saplings and shrubs were made for each plot. Because of the intensive floristic analyses of the bluffs (Wilson 1976, Bryan 1977, Grubbs and Fuller 1991) and the listing of characteristic species (Heineke 1987), less attention was given to the herbaceous layer.

RESULTS AND DISCUSSION

A total of 27 tree species was recorded from the sampling plots of the loess bluffs. In general, vegetation differences among sampling sites were mainly in the relative importance of major species rather that in floristic composition. For that reason a composite table for all stands is presented (Table 1).

In terms of IVs, the leading tree species were sugar maple (*Acer saccharum*, IV 54.11), beech (*Fagus grandifolia*, IV 51.45), and sweetgum (*Liquidambar styraciflua*, IV 41.86). These three accounted for >53% of the density and >56% of the basal area in the ravines (Table 1). Other major canopy and subcanopy associates were white oak (*Quercus alba*), tulip poplar (*Liriodendron tulipifera*), black walnut (*Juglans nigra*), slippery elm (*Ulmus rubra*), hophornbeam (*Ostrya virginiana*), white ash (*Fraxinus americana*), and white basswood (*Tilia heterophylla*). Braun (1950) considered white basswood to be an indicator species for the mixed mesophytic forest. Here it and cucumber magnolia (*Magnolia acuminata*) are disjuncts at the western edge of their ranges (Little 1970). Although cucumber magnolia was of minor importance, Bryan (1977) recognized it as a loess bluff indicator.

In addition to hophornbeam, other commonly encountered understory trees and shrubs included *Cornus florida*, *Asimina triloba*, *Cercis canadensis*, *Hydrangea arborescens*, *Lindera benzoin*, *Styphylea trifoliata*, and *Aralia spinosa*. The seedling/sapling strata were composed of the canopy

Table 1.—The number of trees/ha (N), relative frequency (RF), relative density (RD), relative dominance (RDo), and importance values (IV) of the tree species of the loess bluffs of the Jackson Purchase of Kentucky

	N	RF	RD	RDo	IV
Acer saccharum	78.5	15.54	27.07	11.50	54.11
Fagus grandifolia	33.2	11.92	11.46	28.07	51.45
Liquidambar styraciflua	42.3	10.36	14.63	16.87	41.86
Quercus alba	13.4	5.18	4.63	8.84	18.65
Liriodendron tulipifera	17.6	5.70	6.10	6.12	17.92
Ulmus rubra	14.1	6.74	4.88	3.04	14.66
Ostrya virginiana	15.5	6.74	5.37	0.82	12.93
Juglans nigra	7.8	4.15	2.68	5.48	12.31
Fraxinus americana	11.3	4.66	3.90	2.64	11.20
Carya cordiformis	5.7	3.63	1.95	3.01	8.59
Tilia heterophylla	7.8	2.59	2.68	3.29	8.56
Sassafras albidum	8.5	4.15	2.93	0.75	7.83
Quercus muehlenbergii	5.7	3.63	1.95	1.28	6.86
Quercus velutina	3.5	2.07	1.22	2.60	5.89
Celtis occidentalis	5.7	2.07	1.95	0.98	5.00
Carya glabra	4.9	2.07	1.71	0.92	4.70
Carya ovata	2.8	2.07	0.98	0.21	3.26
Robinia pseudoacacia	2.2	1.04	0.73	0.85	2.62
Quercus rubra	1.4	1.04	0.49	0.99	2.52
Cornus florida	2.2	1.04	0.73	0.09	1.86
Paulownia tomentosa	1.4	0.52	0.49	0.40	1.41
Nyssa sylvatica	0.7	0.52	0.24	0.65	1.41
Acer negundo	0.7	0.52	0.24	0.30	1.06
Magnolia acuminata	0.7	0.52	0.24	0.20	0.96
Prunus serotina	0.7	0.52	0.24	0.03	0.79
Morus rubra	0.7	0.52	0.24	0.02	0.78
Asimina triloba	0.7	0.52	0.24	0.02	0.78
Totals	289.5	100.03	99.97	99.97	299.97

species, especially sugar maple. Wilson (1976) listed 447 taxa and Bryan (1977) 307 taxa of vascular plants for the loess bluffs. Over 18% of the 889 taxa reported for Hickman County were from loess or rich moist woods (Grubbs and Fuller 1991).

Most portions of the bluffs have experienced various degrees of disturbance, however, the forest remnants sampled were little disturbed as judged by their coefficients of determination ($100r^2$ 82-92) (Schmelz and Lindsey 1965). All species were native except for princess tree (*Paulownia tomentosa*). Wilson (1976) listed princess as a characteristic species for Sandy Branch in Carlisle County.

Tree species composition of these forest remnants compares favorably to what was reported over 100 years ago (DeFriese 1880, 1884, Loughridge 1888). The forests on the damp white-sandy soils [loess] near Columbus, Kentucky included "white oak, liriodendron, black and red oaks, white walnut, ash, considerable sugar maple, hickory, sweetgum, black gum, elms, pawpaw, and redbud" (DeFriese 1880). Loughridge (1888) noted that the original forests included, "oaks (white, chinquapin, black and spanish), hickory, walnut, tuliptree, basswood, elm, beech, pawpaw, sweet and black gum, large sassafras and a dense undergrowth of cane".

Tree density varied from 217-400 trees/ha and averaged 289.5. The average basal area was 27.2 m^2/ha with the maximum of 31.5 m^2/ha. Those values are within the range of such characteristics in other mixed mesophytic forests (Martin 1992, Held and Winstead 1975). Species diversity (H') for the combined sample was 3.66 but for individual stands ranged from 3.01 - 3.52. Those values are comparable to those found for all-deciduous mixed mesophytic forests (Monk 1967, Bryant 1988, Martin 1992). The contributions of several species to the community is reflected by an equitability of .77 which agrees with equitability >.50 for mixed mesophytic forests (Martin 1992).

Throughout their N-S length, the loess bluffs are situated between the swamps and bottomland hardwoods of the Mississippi River floodplain to the west and the oak-hickory uplands to the east (Davis 1923). Caplenor (1968) concluded that the mixed hardwood forests of the deep loess in Mississippi were composed of species from the Mixed Mesophytic, Western Mesophytic, bottomland hardwood and the Southern mixed hardwood forests. Miller and Neiswender (1987a, b) found the bluff forests to be somewhat distinct from adjacent communities. Loughridge (1888) noticed that the characteristic vegetation of the bottoms extended to the uplands because of the loess deposits. Sweetgum was the only important tree species in both the bottomland hardwoods and loess bluffs (Bryant 1990, Miller and Neiswender 1989).

Miller and Neiswender (1987a, b) found greater similarity between the forests of the Chickasaw Bluffs and the Appalachians of east Tennessee than to adjacent communities on thin loess. Coefficients of similarity between the bluff forests of the Purchase and the sugar maple-basswood-tuliptree and beech-sugar maple communities of the Lilley Cornett Woods (Martin 1975) in eastern Kentucky were ≈ 48% each. The similarity to the old growth composite for Lilley Cornett Woods (Muller 1982) was >49%. These similarities are about the same as reported by Caplenor (1968) and Miller and Neiswender (1987a, b, 1989).

Braun (1950) observed that the loess bluffs may show stronger vegetational similarities to the forests on the dissected glacial deposits in the Illinoian Drift Area than to the Appalachians. Indeed, similarities between the loess bluffs and the dissected Kansan (Bryant 1978) and Illinoian Drift (Jackson and Allen 1969, Held and Winstead 1976, Bryant 1988, unpub.) of Kentucky, Indiana and Ohio ranged from 41-61%. The average similarity for the 15 stands that were compared to the bluffs composite was >54%. These somewhat higher values seem to support Braun's (1950) observations and may give support for her placing the Jackson Purchase in the transitional Western Mesophytic Forest rather than the Oak-Hickory.

The phytogeographical significance of the loess bluffs, especially the Tunica Hills near their southern terminus, was mentioned by Braun (1950) but given emphasis by Delcourt and Delcourt (1975). Braun (1950) interpreted the mesophytic communities of the loess bluff ravines to be Tertiary relics. On their maps, Delcourt and Delcourt (1981) showed there to be refugial areas of mixed hardwood forests along the bluffs that dated from 40,000 yr. B.P. These communities were relics persisting from the late Pleistocene migrations (Delcourt and Delcourt 1975, 1981).

Mesic species, beech, sugar maple, and basswood, collectively accounted for <1% of the trees in the 1820 General Land Office Survey of the Jackson Purchase (Bryant and Martin 1988). Oaks and hickories were the major species in that survey totalling 72% of the trees. The low percentages for the mesic members seem to indicate their limited or confined distribution in the Purchase. The percentage occurrences (RD) for each of the 27 tree species in the loess bluff ravines were compared to their collective RDs in 63 other upland and lowland survey stands in the Jackson

Purchase (Bryant unpub.). The presence of 12 species, sugar maple, beech, sweetgum, black walnut, basswood, slippery elm, hophornbeam, bitternut hickory, white ash, sassafras, hackberry and chinquapin oak, in the bluff ravines relative to other habitats was highly significant ($p >.001$, z-test). A thirteenth species, cucumber magnolia, was confined to the bluffs. Six other species, white oak, black oak, shagbark hickory, pignut hickory, dogwood and blackgum, were significant for their lack of importance in the bluff ravines relative to other habitats ($p > .001$, z-test). The near confinement of a number of these mesic species in the Jackson Purchase to the bluff ravines may support to their refugial nature (Braun 1950, Delcourt and Delcourt 1975, 1981, 1983, Heineke 1987) as may the presence of disjuncts (Little 1970).

LITERATURE CITED

Bennett, H.H. 1921. The Soils and Agriculture of the Southern States. Macmillan Co., N.Y.

Braun, E.L. 1950. Deciduous Forests of Eastern North America. Blakiston Co. Philadelphia, PA.

Bray, J.R. and J.T. Curtis. 1957. Ordination of the upland forest communities of southern Wisconsin. Ecol. Monogr. 27:325-349.

Brown, C.A. 1972. Wildflowers of Louisiana and Adjoining States. Louisiana State Univ. Press. Baton Rouge, LA.

Bryan, C.A. 1977. A floristic survey of the vascular plants in Loess Bluff Ravines in Carlisle, Hickman, and Fulton Counties in Kentucky. M.S. thesis. Murray State Univ., Murray, KY.

Bryant, W.S. 1978. Vegetation of the Boone County Cliffs Nature Preserve, a forest on a Kansan outwash deposit in northern Kentucky. Trans. Ky. Acad. Sci. 39:12-22.

Bryant, W.S. 1987. Structure and composition of the old-growth forests of Hamilton County, Ohio and environs. pp. 317-327 In: Hay, R.L., F.W. Woods and H. DeSelm (eds.). Proc. VI Central Hardwood Conference. Knoxville, TN.

Bryant, W.S. 1990. Sugarberry (Celtis laevigata) and its associates in the bottomland forests of the Jackson Purchase of Kentucky. pp. 93-100 In: Hamilton, S.W. and M.T. Finley. (eds.). Proc. of the Third Annual Symposium on Natural History of Lower Tennessee and Cumberland River Valleys. Center for Field Biology. Austin Peay State University, Clarksville, TN.

Bryant, W.S. and W.H. Martin. 1988. Vegetation of the Jackson Purchase of Kentucky based on the 1820 General Land Office Survey. pp. 264-276. In: Snyder, D.H. (ed.). Proc. of the First Annual symposium on the Natural History of Lower Tennessee and Cumberland River Valleys. The Center for Field Biology. Austin Peay State University, Clarksville, TN.

Caplenor, D. 1968. Forest composition on loessal and non-loessal soils in west-central Mississippi. Ecology 49:322-331.

Clark, G.T. 1977. Forest communities of Crowley's Ridge. Arkansas Acad. Science Proc. 31:34-37.

Davis, D.H. 1923. The Geography of the Jackson Purchase. Ky. Geol. Surv., Frankfort, KY.

DeFriese, L.H. 1880. Report on the timbers of the district west of the Tennessee River, commonly known as the Purchase District. In: Geol. Surv. of Kentucky 5:125-158.

DeFriese, L.H. 1884. Report on a belt of Kentucky timbers, extending east and west along the south-central part of the state, from Columbus to Pound Gap. In: Geol. Surv. of Kentucky: Timber and Botany 171-232.

Delcourt, H.R. and P.A. Delcourt. 1974. Primeval magnolia-holly-beech climax in Louisiana. Ecology 55:638-644.

Delcourt, H.R. and P.A. Delcourt. 1975. The Blufflands: Pleistocene pathway into the Tunica Hills. Amer. Midl. Nat. 94:385-400.

Delcourt, H.R., P.A. Delcourt and E.C. Spiker. 1983. A 12000-Year record of forest history from Cababa Pond, St. Clair County, Alabama. Ecology 64:874-887.

Delcourt, H.R. and P.A. Delcourt. 1981. Vegetation maps for eastern North America: 40,000 YR B.P. to the present. Geobotany II:123-165.

Dicken, S.N. 1935. The Kentucky Barrens. Bull. Geogr. Soc. Phila. 43:42-51.

Grubbs, J.T. and M.J. Fuller. 1991. Vascular flora of Hickman County, Kentucky. Castanea 56:193-214.

Heineke, T.E. 1987. The flora and plant communities of the Middle Mississippi River Valley. Ph.D. diss. Southern Illinois Univ. Carbondale, IL.

Held, M.E. and J.E. Winstead. 1975. Basal area and climax status in mesic forest systems. Annals of Botany 39:1147-1148.

Held, M.E. and J.E. Winstead. 1975. Structure and composition in a climax forest system in Boone County, Kentucky. Trans. Ky. Acad. Sci. 37:57-67.

Jackson, M.T. and P.R. Allen. 1969. Detailed studies of old-growth forests in Versailles State Park, Indiana. Proc. Ind. Acad. Sci. 59:82-94.

Little, E.L., Jr. 1970. Endemic, disjunct and northern trees in the Southern Appalachians. pp. 249-290. In: Holt, P.C. (ed.). The Distributional History of the Biota of the Southern Appalachians. Part II: Flora. Res. Div. Monogr. 2. Virginia Polytechnic Institute and State University. Blacksburg, VA.

Loughridge, R.N. 1888. Report on the Geological and Economic Features of the Jackson Purchase Region. Ky. Geol. Surv. Frankfort, KY.

Magurran, A.E. 1988. Ecological Diversity and Its Measurement. Princeton Univ. Press. Princeton, NJ.

Martin, W.H. 1975. The Lilley Cornett Woods: a stable mixed mesophytic forest in Kentucky. Bot. Gaz. 136:171-183.

Martin, W.H. 1992. Characteristics of old-growth mixed mesophytic forests. Natural Areas Journal 12:127-135.

McFarlan, A.C. 1943. Geology of Kentucky. Univ. of KY. Press. Lexington, KY.

Miller, N.A. and J. Neiswender. 1987a. A vegetational comparison study of the Third Chickasaw Loess Bluff, Shelby County, Tennessee. Castanea 52:151-156.

Miller, N.A. and J. Neiswender. 1987b. Plant communities of the Third Chickasaw Loess Bluff and Mississippi River alluvial plain, Shelby County, Tennessee. J. Tenn. Acad. Sci. 62:1-6.

Miller, N.A. and J. Neiswender. 19898. A plant community study of the Third Chickasaw Bluff, Shelby County, Tennessee. J. Tenn. Acad. Sci. 64:149-154.

Miller, N.A. and M.E.G. Holyfield. 1986. Old field succession on the loessal soil of the Third Chickasaw Bluff of West Tennessee. J. Tenn. Acad. Sci. 61:57-62.

Monk, C.D. 1967. Tree species diversity in the eastern deciduous forest with particular reference to north central Florida. Amer. Nat. 101:173-187.

Muller, R.N. 1982. Vegetation patterns in the mixed mesophytic forest of eastern Kentucky. Ecology 63:1901-1917.

Newton, J.H. and R.P. Sims. 1987. Soil Survey of Fulton County, Kentucky. USDA, Soil Cons. Serv. Washington, DC.

Schmelz, D.V. and A.A. Lindsey. 1965. Size-class structure of old-growth forests in Indiana. Forest Sci. 11:258-264.

Shull, C.A. 1921. Some changes in the vegetation of western Kentucky. Ecology 2:120-124.

Soil Conservation Service. unpub. Soil Survey of Carlisle and Hickman Counties, Kentucky.

Wilson, L.M. 1976. A distributional survey of the vascular plants on Sandy Branch in the Loess Bluff Area of Carlisle County, Kentucky. M.S. thesis. Murray State Univ., Murray, KY.

The Missouri Ozark Forest Ecosystem Project

The Effects of Forest Management on the Forest Ecosystem

Brian Brookshire and Carl Hauser[1]

Abstract: The effects of forest management on non-timber resources are of growing concern to forest managers and the public. While many previous studies have reported effects of stand-level treatments (less than 15 ha) on various stand-level attributes, few studies have attempted to document the influence of forest management on the biotic and abiotic characteristics of entire management areas, comprising many stands on hundreds of hectares.

The Missouri Ozark Forest Ecosystem Project (MOFEP) was initiated by the Missouri Department of Conservation in 1990 as a long-term study of typical forest management practices on the plant and animal components of those forests. The study is led by the Department's Wildlife and Forestry Divisions, with cooperation from the University of Missouri.

The study area, located in the Ozark Region of southeastern Missouri, consists of mature upland oak-hickory and oak-pine forest communities. The study design includes three replications of three forest management systems: evenaged, unevenaged and non-manipulative or control. Management units (i.e. replications) range in size from 266 to 527 ha (657 to 1,302 acres), with a total study area of 3,725 ha (9,200 acres). Initial forest treatments will begin in October 1994.

Pre-treatment data is now being collected to investigate the effects of forest management on the composition and spatial distribution of woody and herbaceous vegetation, forest interior birds, reptiles and amphibians, tree canopy insects, forest litter invertebrates, small mammals, tree genetics and nutrient cycling.

INTRODUCTION

Non-timber resources are of growing concern to forest mangers and the public. To the present, most forest managers and scientists have concentrated their efforts on manipulating and studying stands, generally less than 15 ha (37 acres), to achieve or determine a particular result. Therefore, a great deal is known about plant and animal species within the confines of the stand boundaries. Conversely, little is known about the effects of stand level management on the entire ecosystem in which that stand lies.

The Missouri Ozark Forest Ecosystem Project (MOFEP) was initiated by the Missouri Department of Conservation in 1990 with an overall goal of understanding how forest management affects forest ecosystems. Project objectives are:

1. Identify a location and define a design that facilitates the analysis of the effects of forest management on major components of a Missouri Ozark forest ecosystem.

---

[1] Silviculturists, Missouri Department of Conservation, Jefferson City, Missouri 65102.

2. Use information acquired to refine forest management practices in Missouri.

To achieve these objectives, a number of studies have been designed and implemented. Staff from the Conservation Department's Forestry and Wildlife Divisions along with cooperators from several Missouri universities and the U.S. Forest Service are presently conducting research on the MOFEP compartments. These researchers are collecting pretreatment information on the composition and spatial distribution of woody and herbaceous vegetation, forest interior birds, reptiles and amphibians, tree canopy and forest litter invertebrates, small mammals, vegetation diversity and nutrient cycling.

Each of these studies has its own specific objectives. This paper will characterize the vegetation on the MOFEP compartments, and use the forest interior bird project as an example of one of many studies associated with MOFEP. The objectives of these two studies are to determine how evenaged, unevenaged, and non-manipulative forest management affect:

1. Plant species diversity and woody plant composition, structure, growth, quality, health, and condition.

2. Rates of nest parasitism, nest predation, and reproductive success of forest interior songbirds, and densities of selected songbirds.

A recent report on forestry research (National Research Council, 1990) recommends that interdisciplinary forest ecosystem research be increased. This approach is taken in MOFEP.

A long-term ecological study like MOFEP has never been conducted in Missouri. A limited number of landscape level research efforts are currently being pursued in the United States and Canada. Hubbard Brook Experimental Forest (Likens, 1988), H. J. Andrews Experimental Forest (Franklin, 1989, for example) and the Vermont Monitoring Cooperative (Scherbatskoy, pers. comm.) in the United States and Kejimkujik (Elder and Martin, 1989) in Canada all involve ecosystem level research. The Missouri Ozark Forest Ecosystem Project is unique among these because of its location and design.

In addition to a characterization of the MOFEP compartments, this paper will address some of the problems associated with a large-scale, long-term project.

METHODS

Study Area

The Missouri Ozark Forest Ecosystem Project is made up of nine compartments, ranging in size from 260 to 527 ha (657 to 1,302 acres) that are located in Carter, Reynolds, and Shannon Counties in the southeastern Missouri Ozarks (Figure 1). Collectively, these counties are 84% forested with large contiguous blocks separated only by roads and streams (Spencer et al. 1992). Agricultural activity is limited to bottomland corridors along primary and secondary streams.

Geologically, the MOFEP management units are underlain mainly by Ordovician age dolomite with areas of Cambrian age dolomite and Precambrian igneous rock also present (MO Geol. Survey, 1979). Ordovician and Cambrian age dolomites exhibit an aggregate thickness of 3,800 and 2,000 feet, respectively (U.S. Geological Survey, 1961).

Weathering of the Ordovician and Cambrian age dolomites has resulted in a deep mantle of leached, very cherty residuum on the MOFEP compartments (Gott, 1975). The residuum is more than 30.5 m (100 feet) thick with rock outcrops present along streams and steep slopes. Water drains freely through this residuum into subsurface solution channels.

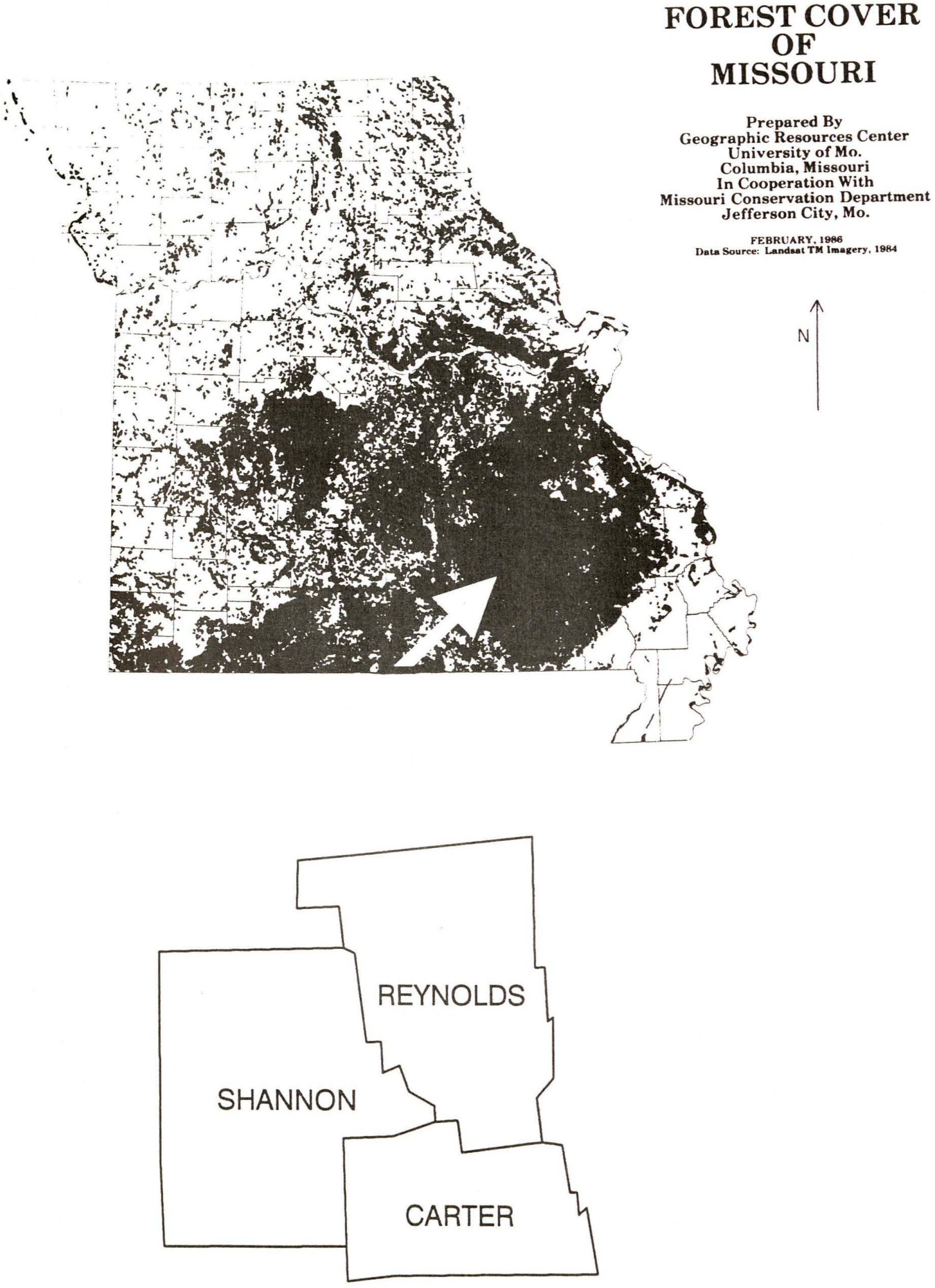

FOREST COVER OF MISSOURI
Prepared By
Geographic Resources Center
University of Mo.
Columbia, Missouri
In Cooperation With
Missouri Conservation Department
Jefferson City, Mo.
FEBRUARY, 1986
Data Source: Landsat TM Imagery, 1984
N
REYNOLDS
SHANNON
CARTER

Figure 1.—Missouri Ozark Forest Ecosystem Study site location.

Mean annual temperature is 13.3° C (56° F), and mean annual precipitation is 112 cm (44 inches). Soils on the compartments were formed mostly in residuum. The common series are Viburnum, Midco, Gepp, Bardley, Viraton, Poynor and Clarksville (SCS unpublished data). A brief description of these series are provided below:

> Viburnum Series - The Viburnum series consists of deep, somewhat poorly drained soils on uplands of the Salem Plateau. These soils formed in thin loess, cherty loamy and clayey sediments, and cherty red clays. Permeability is moderately slow. Slopes range from 1 to 15 percent.
>
> Midco Series - Midco series consists of deep, somewhat excessively drained, cherty soils that occupy the bottom land. They formed in recent alluvium derived largely from upland soils underlain by cherty dolomite and sandstone. The permeability of the soils is moderately rapid. Slope gradients range from 1 to 4 percent.
>
> Gepp Series - The Gepp series consists of deep, well drained, moderately permeable soils that formed in clayey residuum weathered from dolomite and cherty limestone bedrock. These nearly level to steep soils are on uplands in the Ozark Highlands.
>
> Bardley Series - The Bardley series consists of moderately deep, well drained, moderately permeable soils that formed in cherty sediments and residuum from dolomite interbedded with some limestone and sandstone. These soils are on upland ridges, side slopes and nose slopes. Slope gradients range from 2 to 100 percent.
>
> Poynor Series - The Poynor series consists of deep, well drained, moderately permeable soils on uplands formed in residuum from cherty dolomite and clayey shales or cherty limestone. Slope ranges from 2 to 60 percent.
>
> Clarksville Series - The Clarksville series consists of deep, somewhat excessively drained soils formed in residuum and locally transported colluvial-alluvial materials from cherty dolomite or cherty limestone on steep side slopes and narrow ridgetops. Permeability is moderate. Slopes range from 1 to 60 percent.
>
> Viraton Series - The Viraton series consists of deep, moderately well drained soils on foot slopes. These soils formed in loamy and clayey colluvium washed from the adjacent uplands and have a fragipan. Permeability is moderate above the fragipan and very slow in it. Slopes range from 3 to 9 percent.

Management areas within MOFEP are collectively comprised of 13 different Ecological Landtypes (ELT) (Table 1). The ELT of a given area is an index of the capability of that land to support various natural resources (Miller, 1981). The predominant potential productivity class for the compartments is 3.7 to 5.9 cubic meters (131 to 208 cubic feet) of growth per ha (2.47 acres) per year (Spencer et al. 1992). The majority of MOFEP compartments are in the black oak (*Quercus velutina* Lam.) - scarlet oak (*Quercus coccinea* Muenchh.) forest type and range in site index from 51 to 80 (black oak, base age 50) (Hahn, 1991). The individual ELT's and their relative abundance are summarized in Table 2.

Overall Study Design

The Missouri Ozark Forest Ecosystem Project comprises three replications of three treatments in a randomized complete block design. Each treatment area is a standard compartment, 266 to 527 ha (657 to 1,302 acres), in the Missouri Ozarks. All compartments are in the Lower Ozark section of the Ozark Natural Division of Missouri (Thom & Wilson, 1980). All contain mature second growth oak-hickory forest, and no timber harvesting has occurred during the past 20 years. Each compartment was subdivided into from 69 to 74 stands for management purposes.

Table 1.—Description of Ecological Landtypes for the 13 present on MOFEP[1]

ELT	Land form	Aspect	Percent slope	Soil series	Vegetation[2] community
3	High Flood Plain, Low Terrace	Neutral	0-4	Midco	Mesic bottomland forest
5	Upland Waterway	Neutral	0-4	Midco	Dry bottomland forest
7	Toe Slope	All	0-14	Viraton	Mesic forest
11	Ridge	Neutral	0-8	Clarksville Poynor Gepp	Dry chert forest
15	Flat	Neutral	0-8	Viburnum	Dry chert forest
17	Side Slope	South and West	8-99	Clarksville Poynor Gepp	Dry chert forest
18	Side Slope	North and East	8-99	Clarksville Poynor Gepp	Dry-mesic chert forest, Dry-mesic sand forest
19	Side Slope	South and West	8-99	Bardley	Glade savanna
20	Side Slope	North and East	8-99	Bardley	Dry mesic limestone forest
21	Side Slope	All	5-99	Gepp	Dolomite glade Limestone glade
22	Side Slope	All	5-99	Gepp	Xeric limestone forest
23	Side Slope	All	5-99	Gepp	Dry limestone forest

[1] From: Miller, 1981.

[2] From: Nelson, 1985.

Table 2.—Area (and percent) of management compartment in hectares by ELT

ELT	1	2	3	4	5	6	7	8	9	Total
3	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	2 (0.5)	0 (0.0)	2 (0.0)
5	0 (0.0)	0 (0.0)	8 (2.5)	34 (6.8)	22 (8.2)	15 (3.3)	39 (7.8)	26 (7.9)	22 4.7)	166 (4.4)
6	0 (0.0)	15 (2.9)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	15 (0.4)
7	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	9 (1.8)	3 (0.8)	6 (1.3)	18 (0.5)
11	79 (20.7)	117 (22.1)	31 (10.0)	82 (16.7)	39 (14.7)	68 (15.4)	83 (16.5)	48 (14.3)	73 (15.4)	619 (16.6)
15	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	27 (5.4)	32 (9.6)	0 (0.0)	59 (1.6)
17	130 (34.3)	225 (42.7)	108 (35.1)	230 (46.6)	103 (38.8)	212 (47.9)	199 (39.6)	98 (29.4)	237 (50.1)	1542 (41.4)
18	171 (45.0)	170 (32.3)	103 (33.5)	147 (29.9)	95 (35.6)	148 (33.4)	135 (26.9)	87 (26.0)	135 (28.5)	1190 (32.0)
19	0 (0.0)	0 (0.0)	27 (8.8)	0 (0.0)	7 (2.7)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	34 (0.9)
20	0 (0.0)	0 (0.0)	30 (9.8)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	30 (0.8)
21	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.2)	18 (5.3)	0 (0.0)	19 (0.5)
22	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	11 (3.3)	0 (0.0)	11 (0.3)
23	0 (0.0)	0 (0.0)	1 (0.3)	0 (0.0)	0 (0.0)	0 (0.0)	9 (1.8)	10 (2.9)	0 (0.0)	19 (0.5)
Totals	380	527	307	493	266	442	502	334	473	3725

One replication (three compartments) is located on Carr Creek and Cardareva State Forests (numbers 1-3). A second replication is located on Cardareva, Paint Rock and Deer Run State Forests (number 4-6). The final replication is located on Peck Ranch Wildlife Management Area (numbers 7-9) (Figure 1). The treatments will be implemented beginning in the Fall of 1994.

The three treatments are as follows:

1. Evenaged management (EAM) will be practiced according to Missouri Department of Conservation (MDC) Forest Land Management Guidelines (1986), with a rotation length of 80 - 100 years resulting in a regulated harvest of 10% - 12.5% per entry, and a 10 year re-entry period. This is Management Level II in the 1986 Guidelines and approximates the treatments applied to most MDC administered forest land between 1970 and 1986. Under this management level, 10% of each compartment will be left uncut as "old growth", with an objective size class balance of approximately 10% regeneration, 20% small trees, 30% pole timber, and 40% sawtimber. Stand prescriptions will follow Roach and Gingrich (1968). Stands range from one to ten ha (2.5 to 25 acres) in size. In general, total area designated with a silvicultural prescription of regeneration will be restricted to approximately 10% - 12.5% of the compartment, with those stands in greatest need of regeneration selected first. Remaining stands needing regeneration will be deferred to a later entry if possible. Immature stands with site index 55 (base age 50 yrs.) and greater will be given intermediate treatments according to Roach and Gingrich (1968). Glades, food plots, ponds, and other amenities, will be managed according to 1986 guidelines.

2. Unevenaged management (UAM) will be applied under the guidelines of MDC (1986) with stand treatments following Law & Lorimer (1989). Approximately ten percent of each compartment will be designated as "old growth" with no cutting; the remaining 90% will be treated on a 10 year cycle, entered the same years as the EAM treatment. Each compartment will be divided into management units of 8 to 32 ha (20 to 80 acres), and objectives set for largest diameter tree (LDT), residual basal area (RBA), and q-value. The LDT objective will be equal to the desired sawtimber size objective for an identical site under EAM. An overall RBA equivalent to B-level stocking will be chosen, with adjustments made where necessary for anticipated logging damage, etc. Q-value objectives should be in the range of 1.3 - 1.7. A size class distribution identical to that under the EAM treatment would be preferred. For example, a mean poletimber diameter of 21.5 cm (8.5 inches) and sawtimber diameter of 39.4 cm (15.5 inches) (mid points of ranges, assuming 51 cm (20 inch) maximum), with both size classes at B-level stocking, a typical EAM 405 ha (1000 acre) compartment would have 1,784 square m (19,200 square feet) of poletimber basal area and 2,751 square m (29,600 square feet) of sawtimber basal area. According to Law & Lorimer (1989) this is equivalent to a q-value of 1.5.

3. Non-manipulative management (NMM). No cutting for harvest, improvement, or salvage would be permitted. Natural catastrophic events including tornadoes, fire, insect, disease or natural mortality will be treated as if on any other state owned forest land, except that salvage harvests would not occur. Wildfires will be controlled and areas will not be exempted from controls applied to surrounding areas in the event of a large-scale damaging insect outbreak. This treatment will somewhat resemble "old growth" management, and will serve as a control in this project.

The overall study design will allow for analysis of treatment effects within ELT's. For this reason vegetation plots will be randomly assigned within ELT's. A total of 644 permanent plots have been installed to determine adequacy of experimental design (Table 3). The plots will be remeasured after the initial treatment is completed, and at 5 year intervals thereafter. A 0.2 ha (0.49 ac.)

circular plot is used to sample trees 11.4 cm (4.5 in.) dbh and larger and to document the total number of den trees. Four line intercepts 17.2 m (56.4 feet) in length are located within each 0.2 ha (0.49 ac) plot to document the coverage of down dead woody material. Four circular 0.02 ha (0.05 ac.) plots are located within the larger plot to sample woody plants between 3.5 cm (1.5 in.) and 11.2 cm (4.4 in.) dbh. One 0.004 ha (0.01 ac) plot is placed within each 0.02 ha plot (0.05 ac), sharing the same plot center, to sample vegetation taller than 1.0 m (3.3 feet) and less than 3.5 cm (1.5 inches) dbh. Four one square m (10.8 square feet) plots will be located within each 0.02 ha (0.05 ac) plot to sample vegetation less than 1.0 m (3.3 feet) in height. Plot establishment and measurement follow guidelines of Curtis (1983).

Most stands within each compartment contains at least one permanent plot. Stand boundaries do not cross ELT boundaries but one ELT can contain several stands. Table 2 shows the area and percentage of each ELT present in each compartment. The number of permanent vegetation plots within each ELT is proportional to the amount of each ELT present within a compartment (Table 2,3).

Table 3.—Number of vegetation plots by compartment and major ELT

	Compartment									
ELT	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Total**
11	13	15	7	10	8	6	10	8	12	89
17	27	31	30	29	26	37	27	19	31	257
18	33	22	22	24	22	25	23	22	21	214
Other	0	5	13	11	13	3	11	21	7	84
Total	73	73	72	74	69	71	71	70	71	644

RESULTS

Ecological landtypes 11, 17 and 18 comprise the 90% of the MOFEP compartments (Table 2). Therefore, summaries of basal area and stem counts of the six most abundant species growing on the MOFEP sites are limited to these three (Tables 4-9). Across all ELT's black oak (*Quercus velutina* Lam.) accounted for the greatest amount of basal area, ranging from 40% on ELT 11 to 27% on ELT 17. Other species making up the remainder of the total basal area and their relative dominance are summarized in Tables 5, 7 and 9. The total number of stems for each species by compartment is provided in Tables 4, 6 and 8. Diameter class distributions of the six most common species are presented in Figure 2.

Table 4.—Number of trees per hectare by management compartment and dominant species - ELT 11

	Pinus echinata	*Carya* spp.	*Quercus alba*	*Quercus coccinea*	*Quercus stellata*	*Quercus velutina*	*Quercus* spp.	Other spp.	Total
Compartment 1	0.00[1]	0.00	50.00	0.00	0.00	50.00	0.00	0.00	
	190.00[2]	215.00	180.00	170.00	90.00	375.00	10.00	25.00	
	31.92[3]	80.38	109.23	50.00	32.69	157.69	1.15	8.46	471.54
	56.81[4]	58.18	44.29	55.53	28.77	103.49	3.00	8.75	
Compartment 2	0.00	20.00	25.00	0.00	0.00	60.00	0.00	0.00	
	60.00	230.00	320.00	155.00	60.00	290.00	5.00	95.00	
	13.00	122.33	109.33	66.67	11.33	162.67	0.67	25.67	511.67
	20.86	60.26	86.81	46.16	16.53	60.23	1.76	27.96	
Compartment 3	5.00	45.00	85.00	20.00	0.00	70.00	0.00	0.00	
	55.00	90.00	215.00	100.00	40.00	190.00	5.00	10.00	
	23.57	72.86	149.29	48.57	17.86	132.14	1.43	2.86	448.57
	18.87	14.39	46.76	27.34	15.51	48.72	2.44	3.93	
Compartment 4	0.00	30.00	40.00	5.00	0.00	55.00	0.00	0.00	
	205.00	230.00	135.00	285.00	35.00	200.00	5.00	30.00	
	54.00	111.50	93.50	85.00	16.00	128.50	2.00	12.50	503.00
	64.63	78.46	37.79	84.89	12.20	52.02	2.58	11.12	
Compartment 5	0.00	40.00	30.00	5.00	5.00	35.00	0.00	0.00	
	125.00	220.00	155.00	105.00	120.00	185.00	15.00	90.00	
	31.88	131.88	85.00	27.50	54.38	110.63	3.75	29.38	474.38
	45.59	64.97	46.90	32.51	39.14	52.27	5.18	34.17	
Compartment 6	0.00	90.00	30.00	0.00	5.00	45.00	0.00	0.00	
	205.00	230.00	130.00	35.00	80.00	160.00	20.00	65.00	
	54.17	144.17	78.33	11.67	35.83	109.17	3.33	23.33	460.00
	88.11	46.63	40.82	12.52	35.97	46.95	8.16	24.43	
Compartment 7	0.00	0.00	0.00	0.00	15.00	40.00	0.00	0.00	
	275.00	65.00	60.00	330.00	160.00	315.00	45.00	10.00	
	46.50	16.50	29.50	117.50	61.00	138.00	9.00	2.00	420.00
	82.43	19.44	23.27	107.30	39.21	85.90	14.49	3.50	
Compartment 8	0.00	25.00	5.00	5.00	15.00	85.00	0.00	0.00	
	35.00	85.00	60.00	75.00	85.00	285.00	75.00	5.00	
	13.13	48.75	21.88	41.25	45.00	138.13	23.75	0.63	332.50
	12.52	21.00	17.92	27.61	23.30	63.92	28.75	1.77	
Compartment 9	0.00	15.00	0.00	5.00	0.00	55.00	0.00	0.00	
	70.00	115.00	140.00	135.00	110.00	300.00	75.00	10.00	
	14.58	53.75	42.50	41.67	47.92	125.83	12.50	2.92	341.67
	20.39	31.20	43.30	37.01	31.08	62.88	25.09	3.96	

---

[1] Minimum
[2] Maximum
[3] Mean
[4] Standard deviation

Table 5.—Basal area (sq M/ha) by management compartment and dominant species - ELT 11

	Pinus echinata	*Carya* spp.	*Quercus alba*	*Quercus coccinea*	*Quercus stellata*	*Quercus velutina*	*Quercus* spp.	Other spp.	Total
Compartment 1	0.00[1]	0.00	0.84	0.00	0.00	1.76	0.00	0.00	
	8.79[2]	5.95	5.83	6.65	8.10	17.70	0.19	2.38	
	1.64[3]	2.44	2.90	2.42	2.07	9.69	0.03	0.32	21.51
	2.65[4]	1.70	1.35	2.43	2.28	5.08	0.07	0.67	
	8%	11%	13%	11%	10%	45%	0%	1%	100%
Compartment 2	0.00	0.43	1.05	0.00	0.00	2.85	0.00	0.00	
	2.19	8.04	7.73	10.64	7.16	13.04	0.25	4.91	
	0.52	2.98	3.46	3.91	0.91	9.12	0.03	1.19	22.12
	0.73	1.70	2.12	3.23	1.85	2.85	0.08	1.49	
	2%	13%	16%	18%	4%	41%	0%	5%	100%
Compartment 3	0.36	1.77	2.86	1.29	0.00	5.60	0.00	0.00	
	3.42	4.68	12.16	3.77	2.76	16.32	0.38	0.18	
	1.44	2.90	5.56	2.40	1.28	9.11	0.10	0.04	22.84
	1.26	1.01	3.40	0.93	1.02	3.48	0.17	0.07	
	6%	13%	24%	10%	6%	40%	0%	0%	100%
Compartment 4	0.00	0.67	0.83	0.22	0.00	2.41	0.00	0.00	
	9.13	6.85	4.56	17.53	3.00	14.33	0.72	1.20	
	2.88	3.00	3.08	5.86	0.86	8.47	0.10	0.30	24.55
	3.14	2.02	1.18	4.99	0.92	3.62	0.22	0.39	
	12%	12%	13%	24%	4%	35%	0%	1%	100%
Compartment 5	0.00	0.85	1.18	0.27	0.80	3.50	0.00	0.00	
	5.37	7.79	9.29	4.52	6.41	12.77	0.95	3.15	
	1.36	3.89	4.00	1.58	2.93	7.36	0.20	0.84	22.16
	2.01	2.51	2.71	1.32	2.03	3.06	0.34	1.23	
	6%	18%	18%	7%	13%	33%	1%	4%	100%
Compartment 6	0.00	1.92	1.44	0.00	0.13	3.41	0.00	0.00	
	5.29	9.29	5.64	3.72	6.16	15.53	1.27	3.16	
	1.53	5.21	3.22	0.93	2.41	9.96	0.21	0.72	24.19
	2.41	2.53	1.92	1.41	2.54	5.23	0.52	1.22	
	6%	22%	13%	4%	10%	41%	1%	3%	100%
Compartment 7	0.00	0.00	0.00	0.00	0.95	2.46	0.00	0.00	
	19.52	1.85	4.79	15.88	7.01	21.92	1.26	0.15	
	3.29	0.49	1.22	5.98	2.90	8.21	0.28	0.03	22.40
	5.83	0.57	1.42	5.14	1.99	6.13	0.42	0.05	
	15%	2%	5%	27%	13%	37%	1%	0%	100%
Compartment 8	0.00	1.23	0.30	0.26	0.62	7.89	0.00	0.00	
	2.53	4.31	2.23	10.34	5.10	15.70	3.14	0.14	
	0.85	1.95	1.15	4.98	2.36	11.05	1.02	0.02	23.38
	0.90	1.01	0.65	3.74	1.34	2.63	1.29	0.05	
	4%	8%	5%	21%	10%	47%	4%	0%	100%
Compartment 9	0.00	0.20	0.00	0.13	0.00	3.20	0.00	0.00	
	4.78	6.58	4.61	15.03	8.48	24.72	5.28	0.57	
	0.82	2.31	1.73	3.27	3.73	9.54	0.80	0.10	22.30
	1.35	1.96	1.60	4.16	2.57	5.46	1.72	0.17	
	4%	10%	8%	15%	17%	43%	4%	0%	100%
Grand Mean	1.59	2.80	2.92	3.48	2.16	9.17	0.31	0.39	22.83
Percent Mean	7%	12%	13%	15%	10%	40%	1%	2%	100%

[1] Minimum
[2] Maximum
[3] Mean
[4] Standard deviation

Table 6.—Number of trees per hectare by management compartment and dominant species - ELT 17

	Pinus echinata	***Carya* spp.**	***Quercus alba***	***Quercus coccinea***	***Quercus stellata***	***Quercus velutina***	***Quercus* spp.**	**Other spp.**	**Total**
Compartment 1	0.00[1]	0.00	25.00	25.00	0.00	25.00	0.00	0.00	
	290.00[2]	115.00	305.00	480.00	55.00	220.00	45.00	25.00	
	88.70[3]	33.15	107.59	166.11	15.00	109.63	7.04	5.56	532.78
	73.97[4]	29.36	62.38	117.97	17.97	59.71	11.71	6.70	
Compartment 2	0.00	0.00	10.00	0.00	0.00	0.00	0.00	0.00	
	280.00	190.00	310.00	190.00	70.00	385.00	120.00	160.00	
	39.84	58.87	104.84	83.87	11.94	118.23	16.13	26.13	459.84
	59.90	46.36	73.17	49.34	17.73	81.86	33.58	32.75	
Compartment 3	0.00	5.00	10.00	5.00	0.00	15.00	0.00	0.00	
	185.00	110.00	210.00	495.00	145.00	370.00	60.00	55.00	
	46.50	39.33	98.17	112.50	19.33	137.00	5.00	13.00	470.83
	44.47	29.99	50.15	98.35	32.37	83.49	11.82	13.43	
Compartment 4	0.00	0.00	10.00	10.00	0.00	5.00	0.00	0.00	
	220.00	140.00	230.00	430.00	70.00	185.00	60.00	50.00	
	65.52	50.69	101.38	100.17	18.79	75.17	5.69	13.28	430.69
	60.12	38.03	58.05	77.55	17.86	46.24	12.59	13.65	
Compartment 5	0.00	5.00	5.00	5.00	0.00	10.00	0.00	0.00	
	200.00	105.00	200.00	160.00	120.00	250.00	30.00	55.00	
	48.46	47.88	112.31	63.65	34.23	98.46	5.96	24.80	435.76
	52.30	26.73	54.17	39.26	35.99	59.56	8.00	16.61	
Compartment 6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	545.00	135.00	435.00	190.00	170.00	125.00	15.00	185.00	
	99.86	56.08	119.32	62.30	32.70	55.54	2.30	25.95	454.05
	116.40	34.62	83.81	44.22	43.09	37.63	3.65	34.40	
Compartment 7	0.00	0.00	5.00	15.00	0.00	0.00	0.00	0.00	
	245.00	90.00	120.00	450.00	140.00	240.00	50.00	25.00	
	59.07	19.63	50.00	148.70	36.67	37.96	6.48	4.44	362.96
	63.20	23.33	38.41	93.26	32.23	62.93	12.31	5.77	
Compartment 8	0.00	0.00	0.00	0.00	0.00	35.00	0.00	0.00	
	220.00	90.00	140.00	205.00	210.00	175.00	135.00	25.00	
	34.74	25.00	23.16	36.05	39.47	102.37	30.00	5.26	296.05
	57.87	24.66	39.76	60.34	46.81	38.17	38.37	6.56	
Compartment 9	5.00	0.00	0.00	0.00	0.00	5.00	0.00	0.00	
	90.00	140.00	200.00	230.00	90.00	160.00	115.00	45.00	
	23.57	32.58	75.16	89.52	17.74	75.97	7.58	6.29	328.41
	19.67	32.25	53.67	62.59	19.10	47.41	21.52	10.88	

[1] Minimum

[2] Maximum

[3] Mean

[4] Standard deviation

Table 7.—Basal area (sq M/ha) by management compartment and dominant species - ELT 17

	Pinus echinata	*Carya* spp.	*Quercus alba*	*Quercus coccinea*	*Quercus stellata*	*Quercus velutina*	*Quercus* spp.	Other spp.	Total
Compartment 1	0.00[1]	0.00	0.64	1.64	0.00	0.62	0.00	0.00	
	10.14[2]	3.41	7.12	12.07	4.19	9.49	2.02	1.50	
	3.20[3]	0.94	3.05	5.69	0.68	4.94	0.28	0.19	18.96
	2.53[4]	0.91	1.58	3.23	1.10	2.59	0.47	0.35	
	17%	5%	16%	30%	4%	26%	1%	1%	100%
Compartment 2	0.00	0.00	0.35	0.00	0.00	0.00	0.00	0.00	
	11.74	7.47	8.42	9.42	4.44	16.02	3.43	5.24	
	1.79	1.74	3.46	3.93	0.54	5.76	0.47	0.99	18.67
	2.41	1.58	2.14	2.69	0.98	3.66	0.99	1.28	
	10%	9%	19%	21%	3%	31%	3%	5%	100%
Compartment 3	0.00	0.06	0.16	0.48	0.00	0.37	0.00	0.00	
	12.79	4.56	8.82	14.33	7.17	15.04	2.41	2.44	
	2.74	1.38	3.34	4.69	0.95	7.41	0.23	0.57	21.31
	3.03	1.13	1.88	3.21	1.40	3.86	0.53	0.62	
	13%	6%	16%	22%	4%	35%	1%	3%	100%
Compartment 4	0.00	0.00	0.21	0.56	0.00	0.08	0.00	0.00	
	10.32	6.64	11.05	11.98	6.35	8.71	1.91	1.67	
	3.03	1.86	3.70	4.70	1.29	4.59	0.23	0.49	19.88
	2.64	1.62	2.34	2.86	1.40	2.79	0.52	0.51	
	15%	9%	19%	24%	6%	23%	1%	2%	100%
Compartment 5	0.00	0.26	0.07	0.09	0.00	0.42	0.00	0.00	
	9.42	3.37	12.17	7.22	7.06	11.25	1.57	1.86	
	2.76	1.58	4.51	3.18	2.23	5.20	0.28	0.64	20.37
	2.77	0.93	2.61	1.97	2.27	3.32	0.40	0.52	
	14%	8%	22%	16%	11%	26%	1%	3%	100%
Compartment 6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	19.15	5.50	12.77	15.52	9.01	11.50	1.12	4.70	
	3.99	1.82	4.36	4.77	1.99	4.59	0.14	0.68	22.34
	4.48	1.30	2.48	4.06	2.62	3.47	0.26	0.96	
	18%	8%	20%	21%	9%	21%	1%	3%	100%
Compartment 7	0.00	0.00	0.12	1.84	0.00	0.00	0.00	0.00	
	13.45	3.64	5.42	18.00	3.78	8.91	2.60	0.32	
	3.64	0.70	1.70	7.99	1.47	1.94	0.27	0.07	17.77
	3.80	0.88	1.52	3.21	1.09	2.99	0.55	0.08	
	20%	4%	10%	45%	8%	11%	2%	0%	100%
Compartment 8	0.00	0.00	0.00	0.00	0.00	1.86	0.00	0.00	
	9.98	3.06	10.09	12.22	8.85	15.83	6.44	1.66	
	1.73	0.78	1.13	2.74	1.78	7.17	1.33	0.16	16.83
	2.95	0.81	2.51	4.13	2.09	3.71	1.85	0.38	
	10%	5%	7%	16%	11%	43%	8%	1%	100%
Compartment 9	0.00	0.00	0.00	0.00	0.00	0.40	0.00	0.00	
	4.18	4.39	9.35	12.50	3.60	13.70	4.65	1.32	
	1.16	1.11	3.41	4.78	0.97	5.29	0.31	0.14	17.16
	1.17	1.07	2.47	2.83	0.99	3.65	0.89	0.30	
	7%	6%	20%	28%	6%	31%	2%	1%	100%
Grand Mean	2.67	1.32	3.18	4.72	1.32	5.21	0.39	0.44	19.26
Percent Mean	14%	7%	16%	25%	7%	27%	2%	2%	100%

[1] Minimum
[2] Maximum
[3] Mean
[4] Standard deviation

Table 8.—Number of trees per hectare by management compartment and dominant species - ELT 18

	Pinus echinata	*Carya* spp.	*Quercus alba*	*Quercus coccinea*	*Quercus stellata*	*Quercus velutina*	*Quercus* spp.	Other spp.	Total
Compartment 1	0.00[1]	5.00	25.00	25.00	0.00	25.00	0.00	0.00	
	200.00[2]	195.00	380.00	305.00	50.00	240.00	5.00	55.00	
	22.73[3]	65.30	125.61	109.55	5.91	108.94	0.15	17.58	455.76
	39.25[4]	46.69	73.86	71.17	12.71	55.63	0.87	14.95	
Compartment 2	0.00	15.00	50.00	15.00	0.00	20.00	0.00	10.00	
	85.00	190.00	180.00	210.00	45.00	200.00	35.00	75.00	
	13.18	90.68	99.09	100.23	2.27	87.50	2.05	36.14	431.14
	28.43	53.21	34.49	55.82	9.60	46.00	7.51	24.49	
Compartment 3	0.00	10.00	40.00	10.00	0.00	5.00	0.00	0.00	
	75.00	225.00	245.00	215.00	30.00	260.00	30.00	70.00	
	18.41	74.09	142.27	85.23	8.41	86.36	1.59	30.23	446.59
	25.09	47.45	66.76	54.61	12.09	63.62	6.43	21.46	
Compartment 4	0.00	20.00	40.00	5.00	0.00	10.00	0.00	0.00	
	75.00	240.00	275.00	180.00	80.00	160.00	75.00	115.00	
	13.13	95.42	123.96	75.63	13.33	69.17	8.75	36.04	435.42
	21.15	53.93	65.57	52.72	22.78	48.09	18.01	33.00	
Compartment 5	0.00	20.00	20.00	10.00	0.00	5.00	0.00	0.00	
	50.00	265.00	295.00	185.00	60.00	160.00	5.00	65.00	
	9.77	105.68	100.68	60.45	10.23	80.00	0.23	23.64	390.68
	12.49	64.20	64.26	42.84	15.70	42.37	1.07	18.97	
Compartment 6	0.00	10.00	40.00	10.00	0.00	0.00	0.00	5.00	
	135.00	250.00	285.00	150.00	20.00	120.00	5.00	140.00	
	13.20	72.60	140.40	66.00	3.20	48.00	0.40	50.80	394.60
	27.83	57.94	68.52	41.13	6.44	33.70	1.38	34.60	
Compartment 7	0.00	0.00	0.00	10.00	0.00	10.00	0.00	0.00	
	235.00	85.00	290.00	230.00	170.00	235.00	10.00	55.00	
	24.13	28.70	62.17	101.74	33.48	91.09	1.74	8.26	351.30
	49.03	22.57	65.21	62.86	36.94	57.19	3.57	11.93	
Compartment 8	0.00	0.00	15.00	20.00	0.00	5.00	0.00	0.00	
	165.00	95.00	210.00	215.00	115.00	220.00	15.00	90.00	
	15.45	28.86	91.82	99.09	26.36	91.14	2.05	18.86	373.64
	34.29	29.68	57.31	58.59	30.09	59.90	3.98	25.40	
Compartment 9	0.00	10.00	0.00	0.00	0.00	5.00	0.00	0.00	
	35.00	160.00	230.00	135.00	70.00	155.00	30.00	55.00	
	3.81	59.76	84.52	54.05	12.86	56.90	2.14	21.43	295.48
	7.73	44.54	59.47	33.64	22.06	42.29	6.63	15.50	

[1] Minimum

[2] Maximum

[3] Mean

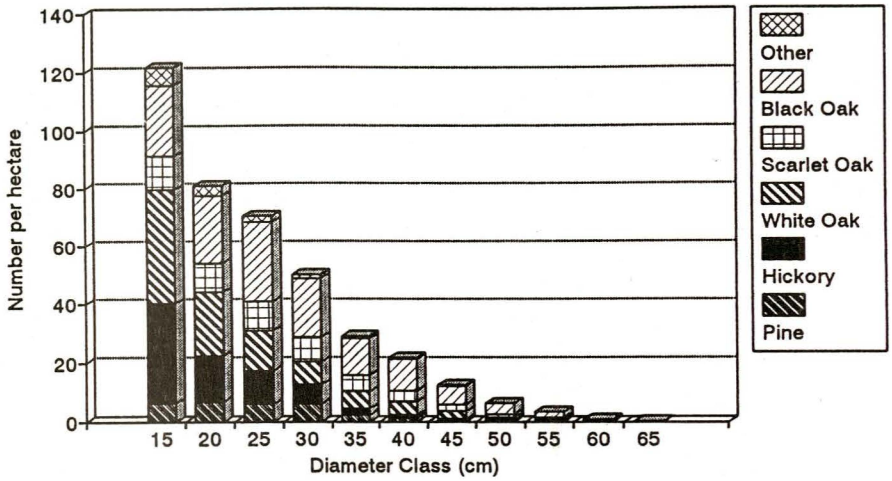
[4] Standard deviation

Table 9.—Basal area (sq M/ha) by management compartment and dominant species - ELT 18

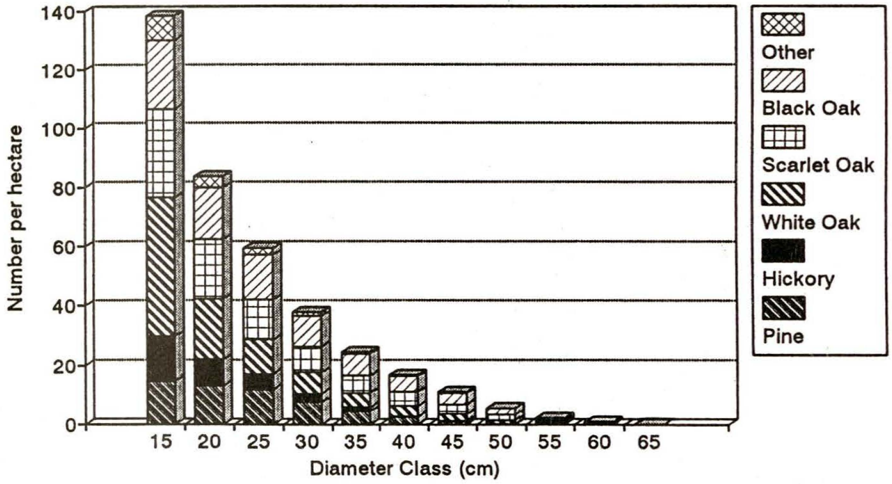
	Pinus echinata	*Carya* spp.	*Quercus alba*	*Quercus coccinea*	*Quercus stellata*	*Quercus velutina*	*Quercus* spp.	Other spp.	Total
Compartment 1	0.00[1]	0.05	0.69	0.76	0.00	1.01	0.00	0.00	
	10.26[2]	6.50	10.43	13.28	3.49	11.72	0.32	3.51	
	1.18[3]	2.14	3.92	5.43	0.32	6.35	0.01	0.63	19.98
	2.03[4]	1.61	2.26	3.03	0.77	3.06	0.06	0.82	
	6%	11%	20%	27%	2%	32%	0%	3%	100%
Compartment 2	0.00	0.20	1.58	0.72	0.00	1.03	0.00	0.10	
	4.63	6.39	7.80	15.78	3.25	12.90	1.19	3.00	
	0.55	2.98	3.29	5.62	0.18	6.16	0.06	1.08	19.94
	1.22	1.99	1.47	3.23	0.70	3.32	0.25	0.86	
	3%	15%	17%	28%	1%	31%	0%	5%	100%
Compartment 3	0.00	0.68	1.36	0.72	0.00	0.35	0.00	0.00	
	5.42	6.02	12.35	9.99	4.06	14.62	1.85	3.17	
	1.06	2.58	4.71	4.79	0.69	6.36	0.09	1.30	21.57
	1.49	1.73	2.22	2.57	1.18	3.79	0.39	0.95	
	5%	12%	22%	22%	3%	29%	0%	6%	100%
Compartment 4	0.00	0.64	1.08	0.37	0.00	0.47	0.00	0.00	
	3.51	9.13	10.17	11.40	5.30	12.19	2.02	4.73	
	0.68	3.20	4.44	4.31	0.86	5.02	0.25	1.30	20.06
	1.08	2.42	2.31	3.18	1.52	3.66	0.53	1.12	
	3%	16%	22%	22%	4%	25%	1%	6%	100%
Compartment 5	0.00	0.54	0.39	0.24	0.00	0.38	0.00	0.00	
	3.74	9.32	9.12	14.96	5.83	12.33	0.20	4.59	
	0.56	3.89	3.82	4.01	0.75	6.11	0.01	0.86	20.02
	0.86	2.47	2.40	3.21	1.34	2.67	0.04	1.16	
	3%	19%	19%	20%	4%	31%	0%	4%	100%
Compartment 6	0.00	0.11	0.90	0.47	0.00	0.00	0.00	0.05	
	4.72	10.22	11.41	13.96	1.63	10.89	0.12	5.89	
	0.59	2.70	6.13	6.06	0.25	5.12	0.01	1.59	22.45
	1.04	2.48	3.04	3.89	0.49	3.61	0.03	1.53	
	3%	12%	27%	27%	1%	23%	0%	7%	100%
Compartment 7	0.00	0.00	0.00	1.51	0.00	0.56	0.00	0.00	
	13.91	4.14	12.80	19.41	6.94	20.81	0.77	0.97	
	1.40	1.16	2.69	7.66	1.52	6.55	0.08	0.14	21.20
	2.85	1.04	3.30	4.74	1.76	5.06	0.20	0.27	
	7%	5%	13%	36%	7%	31%	0%	1%	100%
Compartment 8	0.00	0.00	0.19	1.69	0.00	0.21	0.00	0.00	
	8.72	5.40	12.07	19.79	8.27	16.12	0.61	3.50	
	0.85	1.26	4.30	8.15	1.52	6.27	0.09	0.49	22.93
	1.82	1.57	3.60	5.06	2.06	4.30	0.19	0.84	
	4%	6%	19%	36%	7%	27%	0%	2%	100%
Compartment 9	0.00	0.24	0.00	0.00	0.00	0.12	0.00	0.00	
	3.32	6.99	13.77	10.53	6.87	14.21	0.65	1.63	
	0.37	2.21	4.45	3.86	1.17	4.50	0.07	0.51	17.14
	0.75	1.53	3.64	3.18	2.05	3.77	0.17	0.51	
	2%	13%	26%	23%	7%	26%	0%	3%	100%
Grand Mean	0.80	2.46	4.19	5.54	0.81	5.83	0.08	0.88	20.59
Percent Mean	4%	12%	20%	27%	4%	28%	0%	4%	100%

[1] Minimum
[2] Maximum
[3] Mean
[4] Standard deviation

A. Ecological Landtype 11



B. Ecological Landtype 17



C. Ecological Landtype 18

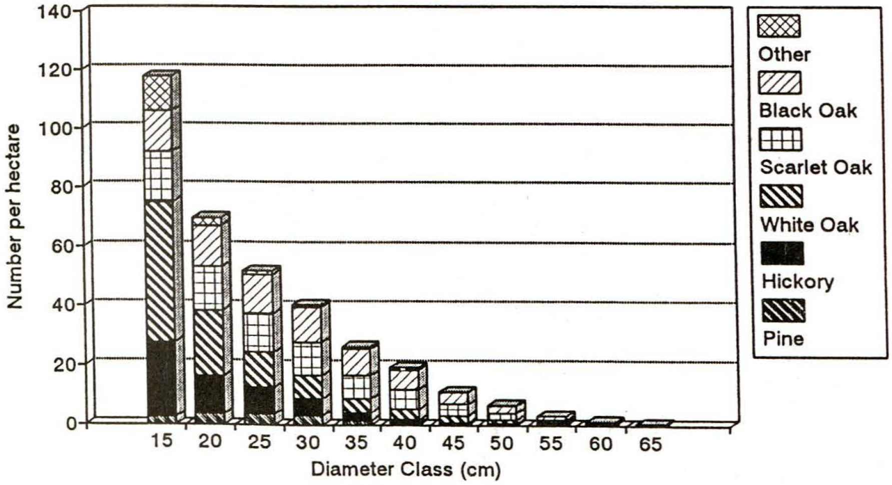


Figure 2.—Number of stems per hectare by size class and major species group. White oak includes post oak.

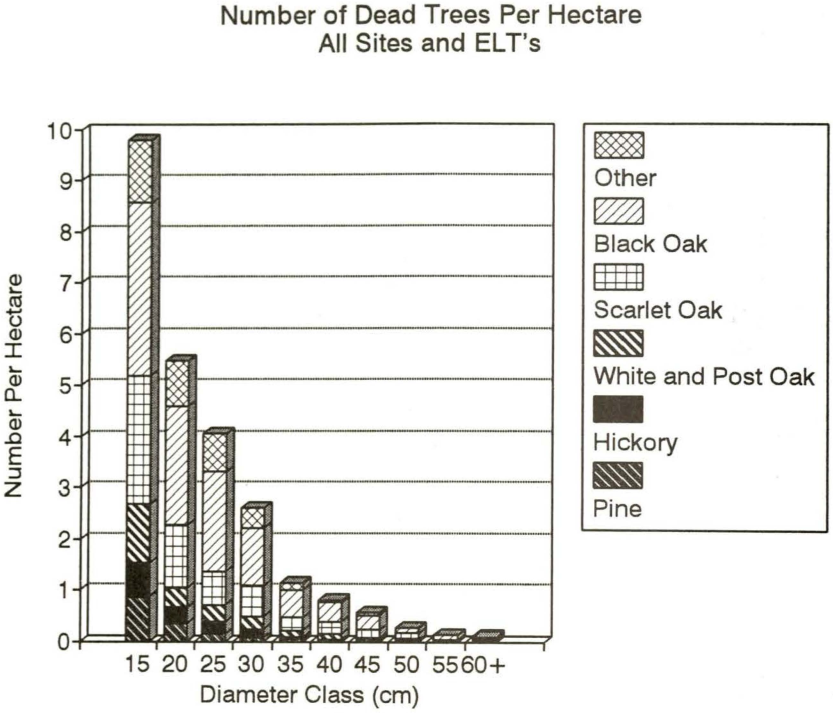


Figure 3.—Size class distribution of dead trees.

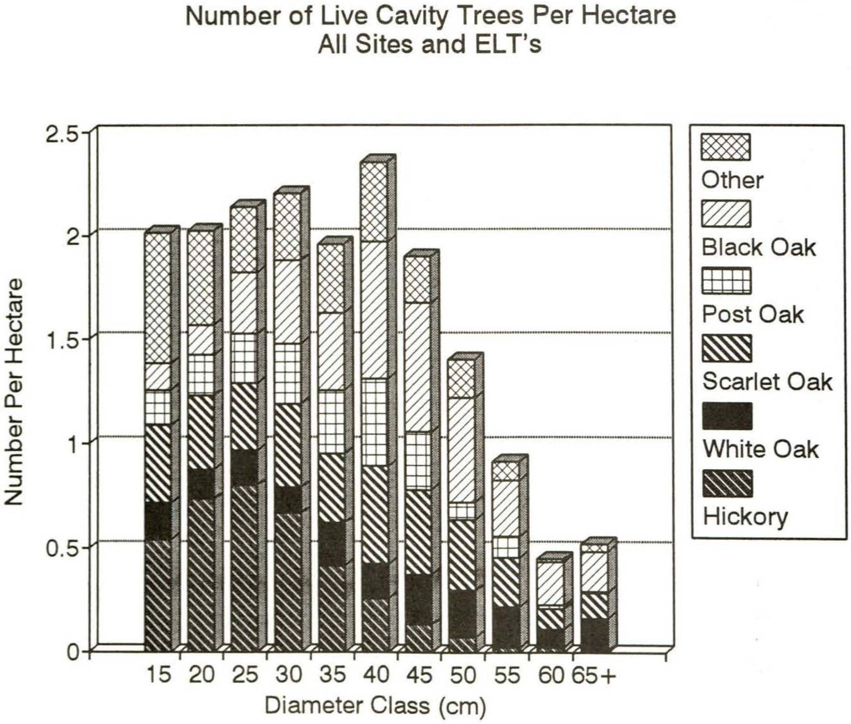


Figure 4.—Size class distribution of all live cavity trees.

Permanent plot establishment resulted in data base of 54,397 standing trees 11.4 cm (4.5 inches) dbh and larger of which 3,741 are dead (Figure 3). Of the 54,397 trees, 2,371 live (Figure 4) and 817 dead trees contain cavities. Additionally, 41,562 trees from 3.8 to 11.3 cm (1.5 and 4.4 inches) in diameter and 26,913 from one meter tall to 3.7 cm (3.1 feet and 1.5 inches) in diameter have been identified and measured. A total of 4,654 pieces of down dead woody material have been documented and over 330 different species of herbaceous plants have been identified and their coverage estimated.

As mentioned previously, a number of independent studies are currently in progress on MOFEP sites. Because of the long term nature of MOFEP, results from these studies from which management recommendations can be made will not be available for many years. However, the preliminary information obtained to date has proven to be very interesting. For example, investigators associated with the forest interior songbird study have collected two years of pretreatment information. Data collected in 1991 and 1992 suggested that nesting success rates were high, nearly 60% for some species and up to 80% for others, and the rate of nest parasitism by brown-headed cowbirds was low, as only eight were parasitized (Clawson, pers. comm.). Nest predation rates were also low, approximately 20%. Approximately 1800 birds have been netted and banded during 1991 and 1992. The results though preliminary, already have proved valuable in the international Partners In Flight program of conservation of neotropical migrant birds.

DISCUSSION

Committing the funding and resources to a long-term project like MOFEP exhibits both forward thinking and a commitment to the proper management of the resource on the part of the Missouri Department of Conservation. These traits were also exhibited by the core group of individuals who were initially involved in proposing MOFEP. A tremendous amount of work and diligence was needed to finally launch a project of this magnitude.

Implementing a long term study like MOFEP can at times be frustrating. The many concurrent interrelated studies demand detailed coordination. The Department Administration has assigned three permanent positions exclusively to MOFEP: a research forester and two assistant research foresters. The research forester is primarily responsible for the forest vegetation study but also serves as the local coordinator for all associated studies.

A large number of people, associated with various MOFEP studies, converge on a very small town in the Missouri Ozarks for three to four months each summer. During the first two to three weeks of the summer the research forester spends much time orienting summer workers to their new quarters and assignments. What would seem to be simple matters, like arranging transportation, can occupy considerable amount of the research forester's time. A research forester coordinating a project like MOFEP on site must be able to handle a multitude of problems that have nothing to do with conducting field research.

Public relations problems in a small town of 1,200 must be addressed. The convergence of many summer workers must be explained to the local people through newspaper articles, group presentations and personal communication. Without adequate explanation, rumors of why so many people associated with the "government" have landed in one small town can be very interesting.

Convincing the public of the authenticity of long term goals of a project like this is difficult. Critics, including the media, frequently believe that research is being conducted to justify current management practices. There is also a tendency for the public to draw premature conclusions. However, these problems can be addressed through diligent attempts to educate the public through the media. In MOFEP, this is being attempted through press releases, tours, exhibits, printed information, and public presentations.

Locating nine parcels of land at least 250 ha in size without previous manipulation for at least 20 years was also a difficult task. These parcels also needed to be within close proximity to each other to facilitate data collection. Fortunately, the heavily forested Ozarks provided the opportunity to conduct a replicated ecosystem level experiment.

The very nature of ecosystem level research requires a tremendous amount of data collection. Identifying and subsequently employing qualified individuals to collect information primarily during the summer months has proven to be very difficult. It is very important to advertise the need for data collectors several months prior to the job starting. Investigators associated with MOFEP have been successful in attracting students from many disciplines from all over the United States to work during the summer months on various projects.

CONCLUSION

Results obtained from MOFEP should help determine the effects of evenaged, unevenaged, and non-manipulative management on major living and non-living components of an oak-hickory forest. Additionally, this project will allow researchers to characterize, with great detail, the major components of an Ozark forest ecosystem and possibly determine how these components interact.

Additional benefits of establishing long term experiments may be significant, but not apparent to us today. Forest ecosystem researchers must be farsighted enough to anticipate problems which might be encountered perhaps 100 years in the future. At the same time, researchers must attempt to solve today's problems. Additional benefits of a long term experiment may be realized in the future when an issue such as gypsy moth, biodiversity, or global warming becomes critical.

LITERATURE CITED

Clawson, R.L. 1992. Personal communication.

Curtis, R.O. 1983. Procedure for establishing and maintaining permanent plots for silvicultural and yield research. USDA For. Serv. Gen. Tech. Rep. PNW-155, PNW For. and Range Exp. Stn. 56p.

Franklin, J. 1989. Toward a new forestry. Am. For. November/December: 37-44.

Gott, J. 1975. Soil survey of the Mark Twain National Forest Area, Missouri (Parts of Carter, Oregon, Ripley and Shannon counties.) USDA Forest Service, Rolla, Mo.

Elder, F.C. and H.C. Martin. 1989. Kejimkujik P - One in a family of integrated watershed studies. Water, air and soil pollution. Vol. 46 Nos. 1-4. pp. 1-12.

Hahn, J.T. 1991. Timber resource of Missouri. USDA For. Serv. N.C. For. Exp. Stn., Res. Bull. NC-119. 123 pp.

Law, J.R. and C.G. Lorimer. 1989. Managing unevenaged stands. In: Central Hardwoods Notes, F.B. Clark and J.G. Hutchison, editors. USDA For. Serv. N. C. For. Exp. Stn., St. Paul, MN. 6 pp.

Likens, P.C. 1988. Publications of the Hubbard Brook ecosystem study. Millbrook, New York. Institute of Ecosystem Studies, Cary Arboretum, Box AB, Millbrook, NY 12545, 124 p.

Miller, M.R. 1981. Ecological Land Classification Terrestrial Subsystem - A basic inventory system for planning and management of the Mark Twain National Forest. USDA Forest Service, Rolla, Mo. 56 p.

Missouri Department of Conservation. 1986. Forest Land Management Guidelines. Mo. Dept. of Cons. 86 pp.

Missouri Geological Survey. 1961. Stratigraphic Succession in Missouri. Mo. Dept. of Natural Resources. Rolla, Mo.

Missouri Geological Survey. 1979. Geologic Map of Missouri. Mo. Dept. of Natural Resources. Rolla, Mo.

National Research Council. 1990. Forestry Research - A Mandate for Change. National Academy Press, Washington D.C. 84 p.

Nelson, P.W. 1985. The Terrestrial Natural Communities of Missouri. M. Dept. of Nat. Res., Jefferson City, Mo. 197 p.

Roach, F.A. and S.F. Gingrich. 1968. Evenaged silviculture for upland central hardwoods. U. S. Dept. of Ag. Handbook 355, Washington, D. C. 39 pp.

Scherbatskoy, T. 1992. Personal communication.

Spencer, J.S. Jr., S.M. Roussopoulos, and R.A. Massengale. 1992. Missouri's Forest Resource, 1989: an Analysis. USDA For. Serv. Res. Bull. NC-139. 84 p.

Thom, R. H. and J. H. Wilson. 1980. The natural divisions of Missouri. In: Transactions of the Missouri Academy of Science. Vol. 14. pp 9-23.

An Ecological Classification System for the Central Hardwoods Region: The Hoosier National Forest

James E. Van Kley and George R. Parker

Abstract: This study, a multifactor ecological classification system, using vegetation, soil characteristics, and physiography, was developed for the landscape of the Hoosier National Forest in Southern Indiana. Measurements of ground flora, saplings, and canopy trees from selected stands older than 80 years were subjected to TWINSPAN classification and DECORANA ordination. Physiographic and soil measurements were regressed on groundflora DECORANA scores. Strong relationships were observed between vegetation and slope aspect, soil A- horizon depth, slope position, and soil pH. The landscape was divided into ecological land units on the basis of these relationships. Twelve ecological units were identified for the Brown County Hills subsection, and fifteen units were identified for the Crawford Upland subsection of the Hoosier National Forest. These ecological units ranged from floodplain forest along large streams to dry forest on southwesterly slopes dominated by species such as blueberry (*Vaccinium vacillans*), common greenbriar (*Smilax rotundifolia*), and chestnut oak (*Quercus prinus*). This classification will aid researchers, naturalists and forestland managers as they deal with complex issues such as resource management and biodiversity.

As a result of growing pressures on forest lands to provide multiple products and amenities, there has been much recent interest in ecological classification systems (ECS) to aid in making ecologically sound management decisions. Ecological classification uses the interrelationships between components of ecosystems such as vegetation, soils, and physiography as the basis for classifying sites across the landscape (Barnes et al. 1982). On federal lands, legislation including the National Environmental Policy Act (1970), the Federal Land Policy and Management Act (1976), and the National Forest Management Act (1976) requires the use of ecological information in decision making (Barnes et al. 1982). Currently, the philosophy of the USDA Forest Service emphasizes an ecosystem approach to land management. To meet such challenges, many ecological classification systems have been developed for various regions of the United States in recent decades.

There have been several approaches to ecological site classification in the United States. The first, habitat typing, originated in eastern Washington and northern Idaho, where R. Daubenmire developed a system containing 22 habitat types (Daubenmire and Daubenmire 1968). Habitat type classifications group sites on the basis of climax or potential natural vegetation: vegetation that would be present on a site in the absence of significant disturbance (Pfister and Arno 1980). Climax vegetation was believed to integrate all of the physical and environmental variables which contribute to a site (Daubenmire 1980). Groundflora vegetation, in particular, has been useful in identifying classification units (Cajander 1926, Daubenmire and Daubenmire 1968, Coffman and Willis 1977, Barnes et al. 1982, Spies and Barnes 1985, Host 1987).

---

[1] Graduate Instructor and Professor, respectively, Department of Forestry and Natural Resources, Purdue University, West Lafayette, IN 47907.

Numerous habitat type systems have been developed. By 1977, 41 classifications were completed or in progress in the western US (Pfister 1977). Many more have been completed since, including Coffman (1980) for the northern Lake States, Alexander et al. (1986) for the Medicine Bow National forest, Wyoming, Cooper et al. (1987), who refined the work of Daubenmire and Daubenmire (1968) in northern Idaho, and Girrard et al. (1989) in South Dakota.

Classifications based primarily on climax vegetation are problematic in the eastern and central states because of the extensive disturbances which these ecosystems experienced following settlement. In the Central Hardwoods, less than one percent of the presettlement old growth forest remains (Parker 1989). Species composition is related to disturbance, chance immigration, successional stage, and other historical factors in addition to environmental site variables. Historical factors are more influential on a disturbed landscape and vegetation on such landscapes may poorly reflect site differences. Moreover, the dramatic environmental gradients associated with elevation changes and the corresponding dramatic influence on vegetation that occur in the montain regions of the west do not occur in the eastern and central states; composition differences are often more subtle.

Another approach is that of Smalley (1979, 1980, 1984) who developed forest site classification systems based mainly on physiography and soils. Woody vegetation was summarized for each classification unit or landtype; however, it is not clear whether each landtype supports a distinct vegetation community (Van Lear and Jones 1987).

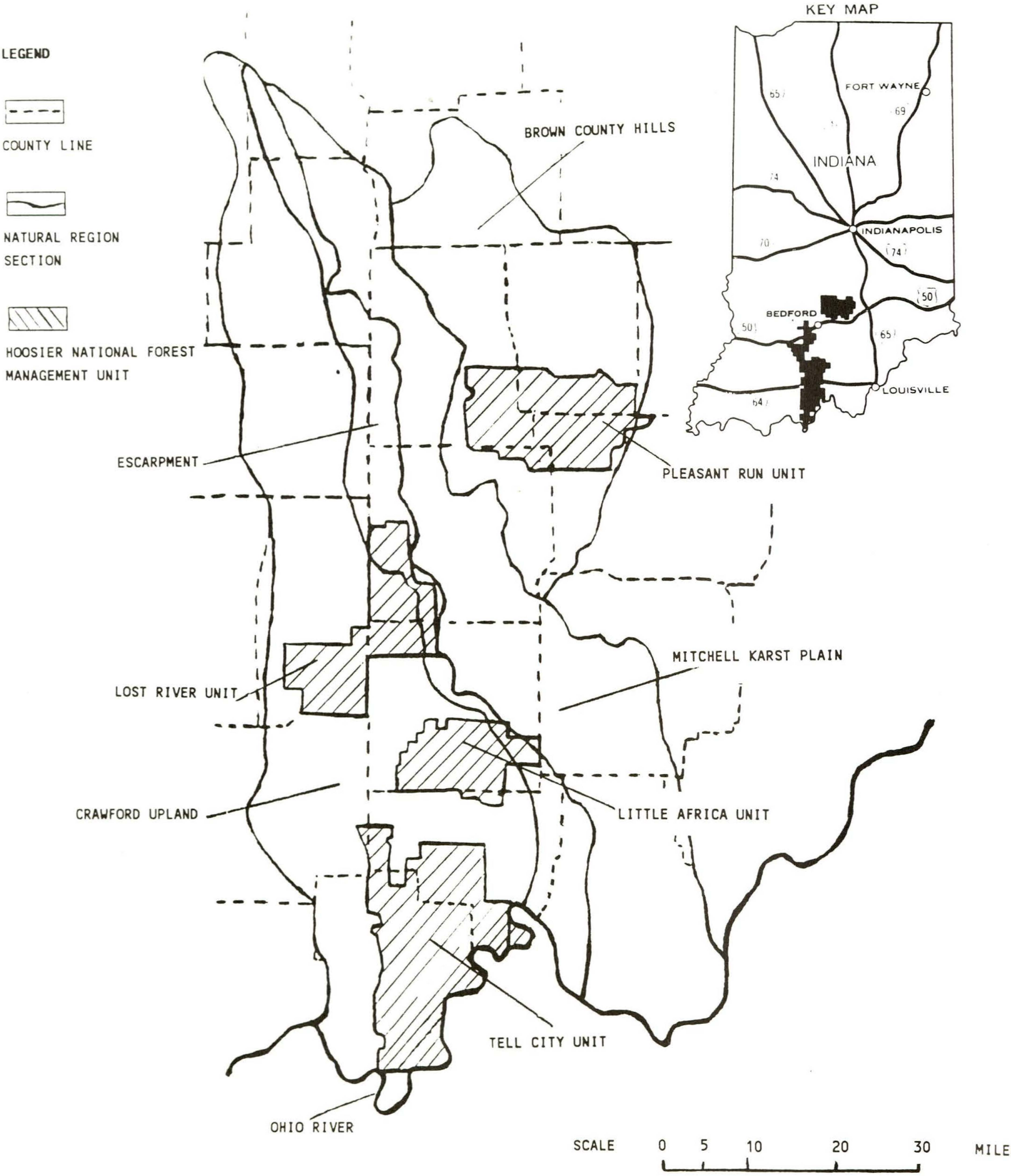
Barnes et al. (1982) describe a multifactor approach to ecological classification in which vegetation and environmental data such as soils and physiography are simultaneously integrated to form ecological classification units. Such systems tend to be more accurate than those based on one component of the ecosystem alone. Systems using the multifactor approach have been developed for the Ottawa National Forest in upper Michigan (Jordan (1982), the Cyrus H. McCormick Experimental Forest in upper Michigan (Pregitzer and Barnes 1984), the Sylvania Recreation area in Michigan's upper peninsula (Spies and Barnes 1985), the Savannah River Plant in the southeastern coastal plain (Van Lear and Jones 1987), and the Kickapoo River watershed in southwestern Wisconsin (Hix 1988). A multifactor ecological classification has also been developed for the Manistee-Huron National Forest in lower Michigan (Host 1987) and systems are being developed for the Hiawatha National Forest in Michigan's upper peninsula and for the Wayne National Forest in southern Ohio.

The objective of this study was to develop a multifactor ecological classification system based on soils, physiography, and vegetation for the Hoosier National Forest in southern Indiana within the Central Hardwoods Region. This system can be used as both a research framework and as a management tool and will be applicable to adjacent public and private lands as well as to the Hoosier National Forest.

METHODS

Study Area

Southern Indiana occurs within the 100 million acre (40 million hectare) Central Hardwoods Region of the east-central United States (Clark 1989). Within the Central Hardwoods, the Hoosier National Forest is located across two of the Natural Regions of Indiana: the Highland Rim and the Shawnee Hills (Homoya et al. 1984). These Natural Regions are further divided into Subsections (Homoya et al. 1984). The Pleasant Run Unit of the Hoosier National forest is located in the Brown County Hills Subsection of the Highland Rim while the remainder of the forest is located in the Crawford Upland Subsection of the Shawnee Hills (Figure 1).



LEGEND
COUNTY LINE
NATURAL REGION SECTION
HOOSIER NATIONAL FOREST MANAGEMENT UNIT
KEY MAP
FORT WAYNE
INDIANA
INDIANAPOLIS
BEDFORD
LOUISVILLE
65
69
74
70
74
50
50
65
64
BROWN COUNTY HILLS
ESCARPMENT
PLEASANT RUN UNIT
MITCHELL KARST PLAIN
LOST RIVER UNIT
CRAWFORD UPLAND
LITTLE AFRICA UNIT
TELL CITY UNIT
OHIO RIVER
SCALE
0
5
10
20
30
MILE

Figure 1.—A map showing the districts of the Hoosier National Forest and the Brown County hills, Mitchel Karst Plain, Escarpment, and Crawford Upland Subsections.

The Brown County Hills Subsection is underlain by mainly Mississippian age siltstones and shales. Soils are chiefly acid silt loams formed from weathered bedrock and a small amount of loess (Homoya et al. 1984). A limestone vein runs along the Mount Caramel Fault through the west side of the region. Deeply dissected uplands, steep slopes, and narrow hollows are typical topographic features of the area.

The Crawford Upland Subsection is characterized by rugged hills with acid silt loams formed in sandstone and loess, and occasional sandstone cliffs and outcrops. The eastern portion is composed of Mississippian sandstone while Pennsylvanian sandstone occurs at the higher elevations in the west (Homoya et al. 1984). While most soils are sandstone-derived, outcrops of shale and thin bands of limestone, calcareous sandstone or calcareous shale can occur throughout the section.

The Escarpment is the transition zone between the Crawford upland and the Mitchel karst plain to the east. (Figure 1). The upper slopes are similar to the Crawford Upland, but the lower areas may contain limestone-derived soils or karst topography (Homoya et al. 1984). Together, the Crawford Upland and Escarpment Subsections encompass the Lost River, Little Africa, and Tell City units of the Hoosier National Forest.

Forests were largely cleared from these landscapes in the late nineteenth and early twentieth centuries for subsistence agriculture. Currently forests cover most of the region with stands generally less than 100 years old. Much of the Brown County Hills Section is publicly owned with the Pleasant Run unit of the Hoosier National Forest, Brown County State Park and Yellowwood State Forest together providing the largest concentration of public land in Indiana.

Classification Hierarchy

The classification presented here is hierarchical, with the upper levels (Domain, Division, and Province) being derived from the ecoregions of Bailey (1989) and the Natural Regions of Indiana (Homoya et al. 1984) forming the middle levels of the hierarchy (Figure 2). The purpose of this study was to develop the lowest two ecological classification levels, the ecological unit groups and the ecological land units.

Data Collection

To minimize effects of historical disturbance on vegetation, all stands listed as greater than 80 years of age in the USDA Forest Service's VIMIS database were selected as potential sample sites. Stands were categorized into 10 land types on the basis of physiography (Table 1). Replicated stands were randomly selected from the pool of stands in each land type, plotted on USGS 1:24000 topographic maps, and field-checked for evidence of excessive disturbance. Reasons for rejection included stumps, underplanting, excessive early successional species, and excessive heterogeneity of physiography within the site. The Brown County Hills and the Crawford Upland\Escarpment Sections of the Hoosier National Forest were sampled and analyzed independently.

During the summers of 1989 to 1992, 66 and 144 stands (Table 1) were sampled in the Brown County Hills and the Crawford Upland/Escarpment Sections respectively. Four subplots were randomly established at each site (Figure 3). Each subplot included a series of nested plots for vegetation sampling. Diameter at breast height (dbh) was recorded for each tree greater than 10cm dbh on a 500m^2 circular plot, while the number of stems of shrubs and saplings less than 10cm dbh but greater than 1m high were tallied for each species in a 100m^2 circular plot. The percentage cover of groundflora species (herbs, vines, and small shrubs) in the 4m by 4m plot was estimated. Raw cover estimates were converted to an octave scale (Gauch 1982) before analysis. Tree seedlings less than 1m high were also counted on each 4m by 4m plot.

A soil pit at the first subplot and bucket augers at the remaining subplots were used to develop a

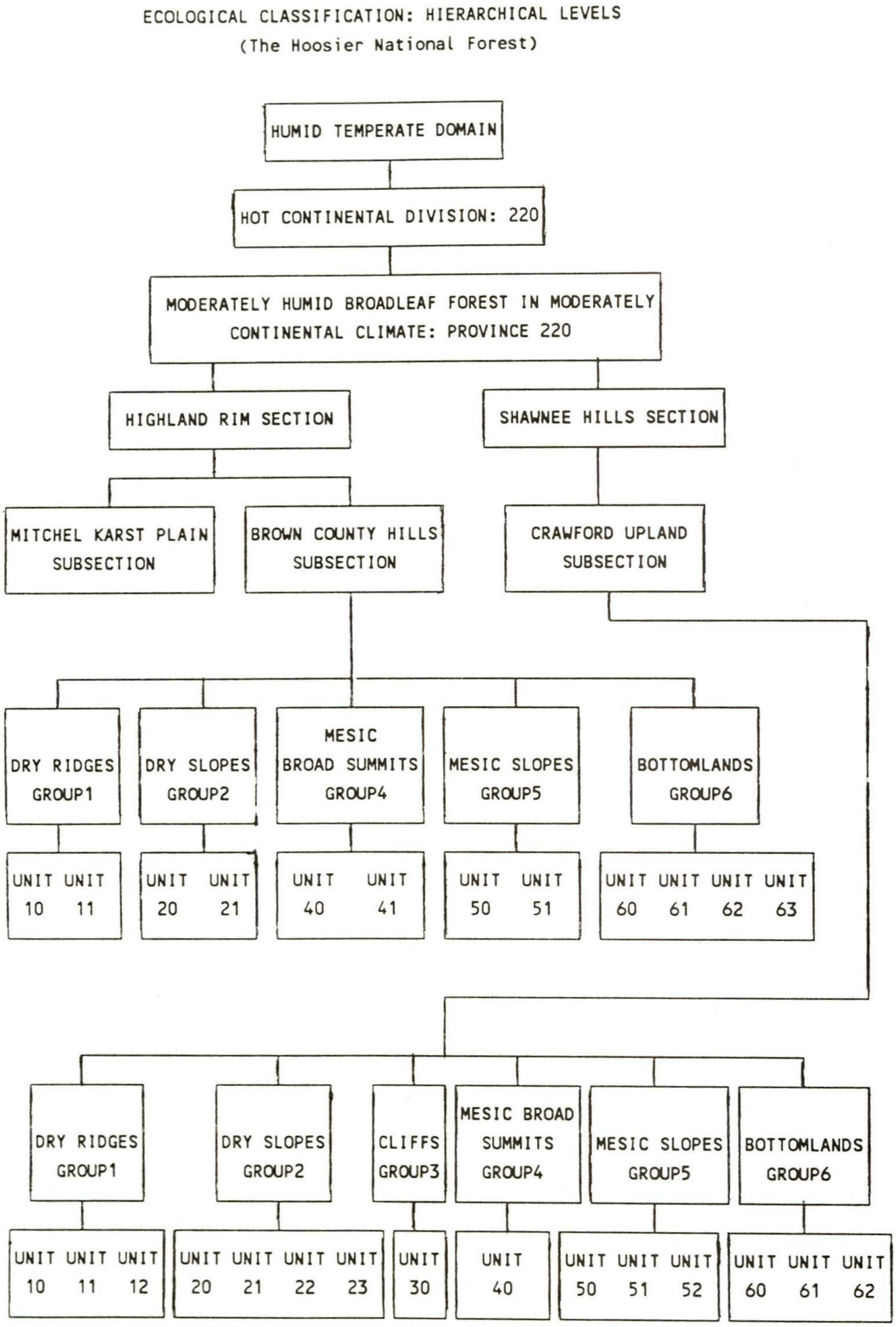

ECOLOGICAL CLASSIFICATION: HIERARCHICAL LEVELS
(The Hoosier National Forest)
HUMID TEMPERATE DOMAIN
HOT CONTINENTAL DIVISION: 220
MODERATELY HUMID BROADLEAF FOREST IN MODERATELY CONTINENTAL CLIMATE: PROVINCE 220
HIGHLAND RIM SECTION
SHAWNEE HILLS SECTION
MITCHEL KARST PLAIN SUBSECTION
BROWN COUNTY HILLS SUBSECTION
CRAWFORD UPLAND SUBSECTION
DRY RIDGES GROUP1
DRY SLOPES GROUP2
MESIC BROAD SUMMITS GROUP4
MESIC SLOPES GROUP5
BOTTOMLANDS GROUP6
UNIT 10 UNIT 11
UNIT 20 UNIT 21
UNIT 40 UNIT 41
UNIT 50 UNIT 51
UNIT 60 UNIT 61 UNIT 62 UNIT 63
DRY RIDGES GROUP1
DRY SLOPES GROUP2
CLIFFS GROUP3
MESIC BROAD SUMMITS GROUP4
MESIC SLOPES GROUP5
BOTTOMLANDS GROUP6
UNIT 10 UNIT 11 UNIT 12
UNIT 20 UNIT 21 UNIT 22 UNIT 23
UNIT 30
UNIT 40
UNIT 50 UNIT 51 UNIT 52
UNIT 60 UNIT 61 UNIT 62

Figure 2.—Classification hierarchy for an ecological classification system of the Hoosier National Forest. The upper levels of the hierarchy (Domain, Division, and Province) derive from the ecoregions of Bailey (1989), while the middle level (Section, Subsection) derive from Homoya et al. 1984).

Table 1.—Ten landtypes based on physiography which were used to stratify the landscape for sampling. BC stands and CU stands are the number of stands sampled for each landtype in the Brown County Hills and Crawford Upland respectively.

Land type	Description	BC Stands	CU Stands
1	Narrow ridges between 30 and 150 feet in width.	12	12
2	Broad, sloping ridges > 150 ft wide, between 8 and 15 % slope.	1	10
3	Broad, flat ridges > 150 ft wide and < 8% slope.	3	4
4	Gentle slope, less than 15%.	5	13
5	Moderate northerly slope: (315° - 135°, 16-30 %.).	6	22
6	Moderate southerly slope: 136° - 314°, 16-30 %).	6	33
7	Steep northerly slope: (315° - 135°, over 30 %).	9	13
8	Steep southerly slope: 136° - 314°, over 30 %).	10	13
9	Major riparian area: (> 200 ft wide).	6	12
10	Minor riparian area: (< 200 ft wide).	8	10

detailed soil profile description. Measurements including depth of the O, A, and B horizons, the depth when present of the E, B_t, B_x, and C horizons, the depth to gray drainage mottles, the pH (tested in the field) for each horizon, the (texture estimated in the field) for each horizon, the percentage coarse fragments in each horizon, the depth of the solum to bedrock or a root-restricting layer, and parent material were recorded.

Physiographic measurements including slope gradient (in percentage), aspect (degrees azimuth), slope shape, relative slope position on a scale of 1 to 100, and elevation in meters above sea level were recorded at each subplot.

Data Analysis

The multivariate ordination technique known as Detrended Correspondence Analysis (DECORANA, Hill 1979a), an improvement of reciprocal averaging ordination, was used to arrange sites along

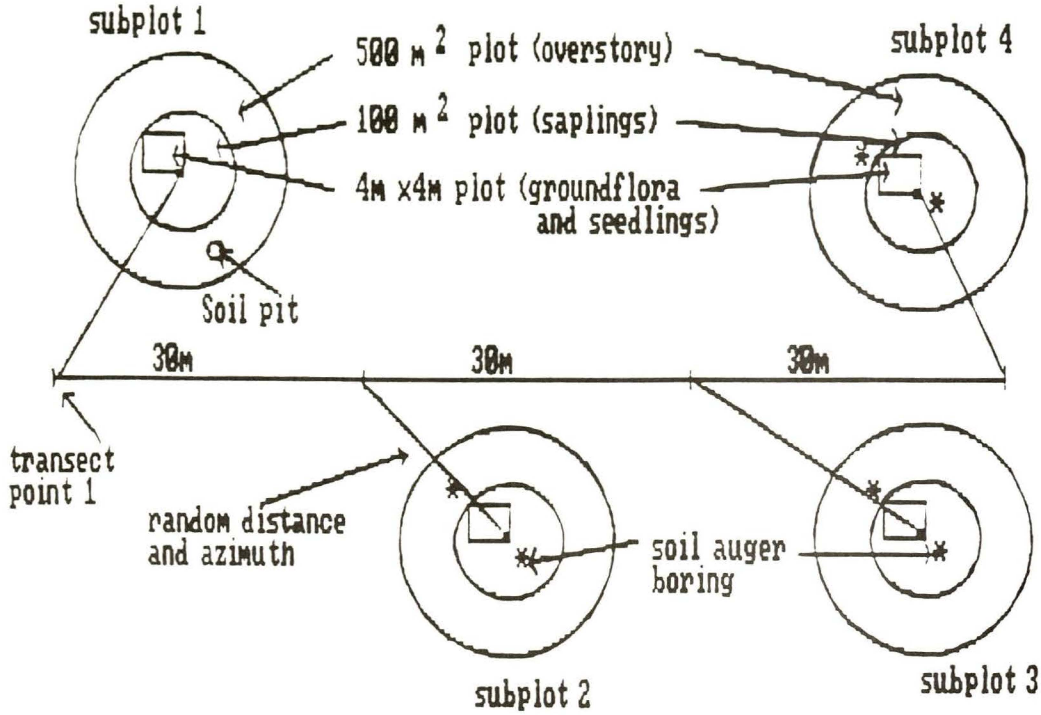


Figure 3.—A diagram of the design used to sample reference sites for an ecological classification system on the Hoosier National Forest.

two or three axes on the basis of the presence and coverage of groundflora species in each site. Sites with similar species composition are close to each other in ordination space but dissimilar sites are separate.

Two Way Indicator Species Analysis (TWINSPAN) is a divisive polythetic classification based on repeated division of a reciprocal averaging ordination space (Hill 1979b). We used TWINSPAN to group sites into classes with similar species composition and species into groups which grow on similar types of sites. These groupings produced an ordered species-by-samples table, and formed the basis for ecological species groups as in Spies and Barnes (1985). Separate ordinations and classifications were used for the groundflora and overstory layers.

Aspect was Cosine-transformed according to Beers et al. (1966) resulting in a value that ranged from 0 (southwest) to 2 (northeast). Mean values for variables relating to physiography, soil horizon development, soil pH, soil depth, and soil texture were calculated for each sample stand.

Forward stepwise multiple regression (Hintze 1988) was used to relate linear changes in the environmental variables above to each DECORANA ordination axis. This approach for integrating ordination results with environmental variables follows "strategy two" of Ludwig and Reynolds (1988).

Sample stands were classified into ecological units on the basis of the groundflora vegetation type identified by TWINSPAN, and on the basis of the soil and physiographic variables most strongly correlated with the groundflora and overstory DECORANA ordination axes.

Indicator species (species that distinguish between two choices at each step of the key) derived from TWINSPAN, species groups also derived from TWINSPAN, and the main soil and physiographic variables were used to develop a field key (Figure 5). This key was used to field-test the ECS and to determine if the relationships identified were consistent and useful in the field. The key will also be used by forestland managers to identify ecological units.

RESULTS

A TWINSPAN classification of the Crawford Upland subsection reference sites on the basis of groundflora revealed eight vegetation types. Since communities were believed to mainly occur along a moisture gradient, the types were named floodplains, moist-mesic, mesic, cliffs, moderately dry, dry oak forest, dry clay post oak forest, and dry clay oak barrens. These groups were corroborated by the DECORANA results (Figure 4). Similar results were observed for the Brown County Hills, but the cliffs, dry clay post oak forest, and dry clay oak barrens were lacking.

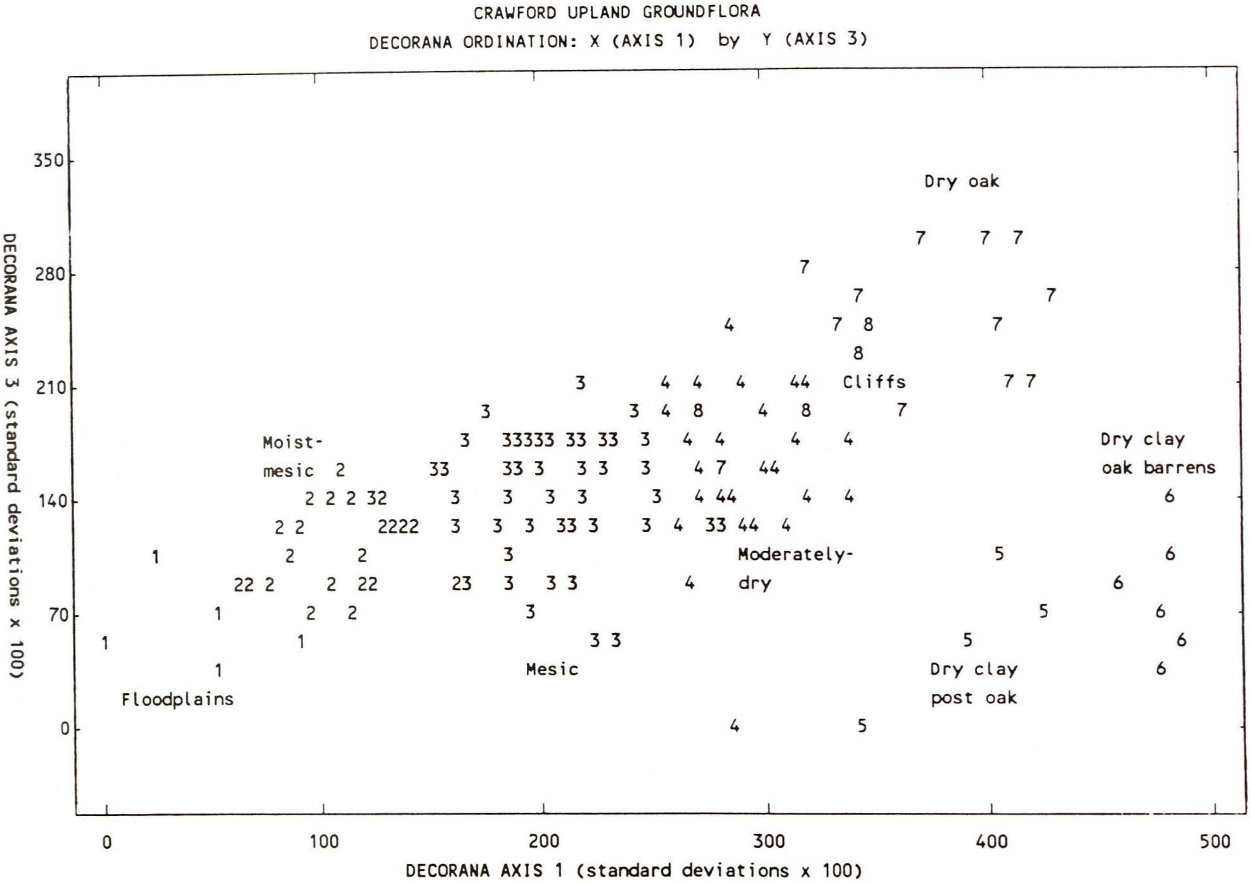


Figure 4.—The first and third axes of a DECORANA ordination of 144 stands from the Crawford Upland on the basis of groundflora. The numerals refer to classification units derived from TWINSPAN. Seven vegetation types (names) resolve on this graph, while type 8 (Cliffs) resolves on axis 2. Most of axis 2 was compressed as a result of variability associated with the cliffs and the floodplains.

Vegetation types were distinguished on the basis of species groups derived primarily from the species classification of TWINSPAN. Indicator species and species groups for the Brown County hills data set were similar for equivalent vegetation types in the Crawford Upland data set.

After selecting the site variables most correlated with axis one DECORANA ordination scores, a final stepwise regression model for the Crawford Upland included eight variables while the model for the Brown County Hills contained six (Table 2). R-squared was 0.74 for the Crawford Upland and 0.87 for the Brown County Hills. In both Subsections, the variables most correlated with axis

A KEY TO THE ECOLOGICAL LAND UNITS OF THE HOOSIER NATIONAL FOREST: KEY 1, THE BROWN COUNTY HILLS.

PART 1: KEY TO THE ECOLOGICAL GROUPS

1a) Site is located in the Brown County Hills section of the Highland Rim Natural Region (The Pleasant Run Unit of the Hoosier National Forest, Yellow wood State Forest, Morgan-Monroe State Forest, Brown County State Park or vicinity)...(2)

1b) Site is located in the Crawford Upland or Escarpment sections of the Shawnee Hills Natural Region (the Lost River, Little Africa, and Tell City Units of the Hoosier National Forest or vicinity) ...(KEY 2)

2a) Upland slope positions ...(3)

2b) Alluvial (bottomland) positions. Vegetation is variable but always mesic, moist mesic, or wet. Smilax rotundifolia is infrequent, rare or absent and dry-site indicators such as Carex picta, Vaccinium vacillans, Danthonia spicata, and Cunila origanoides are usually absent...GROUP 6: BOTTOMLANDS

3a) Summit or upper shoulder (ridgetop) slope positions. Slope gradient is not steep (<10%) ...(4)

3b) Backslope positions. Slope gradient is steeper than 10%...(5)

4a) Ridgetops generally narrower than 75m. Ridgetop is usually convex. Carex picta, Vaccinium vacillans and Smilax rotundifolia are usually common. Other members of the Carex picta ecological species group may be present ...GROUP 1: DRY DGETOPS

4b) Broad, flat ridgetops generally wider than75m. Ridgetop is flat or slightly convex with concave depressions possible. Topography may be gently rolling on larger landforms. Arisaema triphyllum, Galium triflorum, Claytonia virginiana, Osmorhiza claytoni, and Sanicula canadensis are common or abundant. Dentaria laciniata abundant. Overstory contains significant amounts of sugar maple and beech. Members of the Arisaema and Lindera ecological species groups are common...GROUP 4: BROAD MESIC RIDGETOPS.

5a) Aspect is generally southerly (135-315 degrees azimuth). Sites outside this azimuth range with the vegetation described below either have a thin A horizon or occur high on the slope. Mean soil A horizon depth is generally less than 6 cm. Carex picta, vaccinium vacillans and other members of the Carex picta group are present. Members of the Arisaema group, especially Dentaria laciniata may be present, but much less common than for 5b...GROUP 2: DRY SLOPES

5b) Aspect is generally northerly (between 315-135 degrees azimuth) or limestone is present. Mean soil A horizon depth is usually greater than 6cm. Arisaema triphyllum, Galium triflorum, Claytonia virginiana, Sanicula canadensis, Osmorhiza claytoni, and Dentaria laciniata are common or abundant. Other members of the Arisaema, Lindera, and occasionally the Asarum groups are present. Fagus grandifolia and Acer sacharum are common in the overstory of older stands... GROUP 5: MESIC SLOPES.

PART 2 :KEY TO THE ECOLOGICAL LAND UNITS

GROUP 1: DRY RI .ETOPS

1a) Ridgetops with common or abundant parthenocissus quinquefolia. Conopholis americana is often present. Members of the Arisaema ecological species group may be present. Carex picta, vaccinium vacillans, and Smilax rotundifolia generally present but not abundant. Mean Soil A horizon depth is usually greater tr 3.3 cm. ...UNIT 11: QUERCUS, ACER SACHARUM, PARTHENOCISSUS, MODERATELY DRY RIDGETOPS.

1b) Narrow ridgetops with abundant Smilax rotundifolia and Carex picta. Vaccinium vacillans, Cunila origanoides and other members of the Carex picta group are common. Members of the Arisaema group are rare or absent. Mean soil A horizon depth is less than 3.3cm. common. Quercus prinus may be dominant in the overstory...UNIT 10: QUERCUS, VACCINIUM, DRY RIDGETOPS.

Figure 5.—A field key for the Hoosier National Forest ECS which identifies ecological land units on the basis on indicator species, soils and physiography. The first part identifies the correct section (the Brown County Hills) and identifies the ecological unit groups. The second part identifies the individual ecological units of group 1. Subsequent keys (not shown) identify the ecological units of the remaining groups.

Table 2.—Multiple linear regression models relating the dependent variable, groundflora vegetation (as summarized by DECORANA axis 1) to soil and physiographic variables for 66 stands in the Brown county Hills and for 144 stands in the Crawford Upland. (Tr aspect = cosine-transformed aspect: range 0-2, Geo = distance north of the latitude of Tobinsport, IN on the Ohio River).

The Crawford Upland

Independent variable	Parameter estimate	t-value (b=0)	Prob. level	Sequential R-square	Simple R-square
Intercept	429.078	9.01	0.000	-	-
Tr. aspect (0-2)	-44.644	-5.35	0.000	0.24	0.24
Slope gradient (%)	1.112	3.07	0.003	0.29	0.04
slope position (%)	0.977	5.87	0.000	0.50	0.29
Geo (miles)	-1.519	-5.18	0.000	0.55	0.06
A horizon pH	-38.053	-4.53	0.000	0.62	0.20
B horizon clay (%)	2.949	6.17	0.000	0.70	0.15
A horizon depth (cm)	-2.940	-2.31	0.022	0.72	0.43
B horizon depth (cm)	-0.476	-2.97	0.003	0.74	0.05

The Brown County Hills

Independent variable	Parameter estimate	t-value (b=0)	Prob. level	Sequential R-square	Simple R-square
Intercept	-6.359	-0.07	0.946	-	-
Tr. aspect (0-2)	35.872	3.76	0.000	0.11	0.11
Slope position (%)	-1.054	-4.77	0.000	0.55	0.46
Elevation (m)	-0.650	-2.17	0.034	0.67	0.47
A horizon pH	44.205	4.12	0.000	0.78	0.42
A horizon depth (cm)	10.522	4.54	0.000	0.80	0.45
Total solum depth (cm)	0.889	5.29	0.000	0.86	0.23

one were slope position, aspect, A horizon depth, and A horizon pH. B horizon clay was also correlated with axis one for the Crawford Upland. These were the main environmental variables considered when sorting the reference sites into ecological land units and in writing the field key (Figure 5).

The importance of aspect is underestimated in the models in Table 2 because these models include ridgetop and bottomland sites where the effects of aspect are negligible. For models in which only sloping lands are included, the simple r^2 for aspect is 0.40 for the Crawford Upland, and 0.43 for the Brown County Hills.

Soils on most site types were formed in sandstone or siltstone, often with a thin layer of loess. Soil textures were generally silt loams with silty clay loams in the B horizon of soils that possessed argillic horizons (Tables 4, 5). Soil texture differences were not important for distinguishing most ecological units. However, the percentage clay of the B horizon was important in the Crawford Upland for describing the contrast between sandstone cliffs, dry clay barrens and dry oak sites.

The Forest Ecosystems of the Hoosier National Forest

Six groups of ecological units (Table 3) were determined on the basis of physiographic position (whether a site was on a ridgetop, a cliff, a back-slope, or in a bottom) and on the basis of the whether a site had a mesic (type 4-7, figure 3) or a dry (type 1-3) vegetation type.

Table 3.—A list of the ecological units described for the Hoosier National Forest. (*) Units are described for the Crawford Upland and (^) the Brown County Hills only.

GROUP 1: DRY RIDGETOPS

UNIT 10: QUERCUS, VACCINIUM, DRY NARROW RIDGETOPS.
UNIT 11: ACER SACCHARUM, QUERCUS, PARTHENOCISSUS, MODERATELY DRY NARROW RIDGETOPS.
*UNIT 12: QUERCUS STELLATA, VACCINIUM, DRY CLAY RIDGETOPS

GROUP 2: DRY SLOPES

UNIT 20: QUERCUS, VACCINIUM, DRY SLOPES.
UNIT 21: QUERCUS, ACER SACCHARUM, PARTHENOCISSUS, MODERATELY DRY SLOPE
*UNIT 22: QUERCUS STELLATA, VACCINIUM, DRY CLAY SLOPES
*UNIT 23: QUERCUS STELLATA, ERYNGIUM DRY CLAY OAK BARRENS

GROUP 3: CLIFFS

*UNIT 30: ACER RUBRUM, HYDRANGEA, SANDSTONE CLIFFS

GROUP 4: MESIC BROAD SUMMITS

UNIT 40: FAGUS, ACER SACCHARUM, ARISAEMA MESIC BROAD SUMMITS
UNIT 40L: DEGRADED MESIC BROAD SUMMITS
^UNIT 41: ACER SACCHARUM, ARISAEMA-JEFFERSONIA CALCAREOUS MESIC BROAD SUMMITS

GROUP 5: MESIC SLOPES

UNIT 50: FAGUS, ACER SACCHARUM, ARISAEMA, MESIC SLOPES
*UNIT 51: FAGUS, ACER SACCHARUM, ASARUM MOIST-MESIC SLOPES
^UNIT 51: ACER SACCHARUM, JEFFERSONIA MOIST-MESIC LIMESTONE SLOPES
*UNIT 52: ACER SACCHARUM, ARISAEMA-JEFFERSONIA CALCAREOUS MESIC SLOPES

GROUP 6: BOTTOMLANDS

UNIT 60: FAGUS, ACER SACCHARUM, ARISAEMA, MESIC STREAM BOTTOMS
UNIT 61: PLATANUS, ASARUM MOIST-MESIC STREAM BOTTOMS
UNIT 62: ACER SACCHARINUM, BOEHMERIA WET BROAD FLOODPLAINS.
^UNIT 63: ACER SACCHARUM, ASARUM-BOEHMERIA MOIST BROAD FLOODPLAINS

Groups were named with a moisture term and a physiographic description. Ecological units were named for one or two potential dominant overstory species, the species group most typical of the unit, a term describing soil moisture (mesic, moderately dry), and a physiographic description (Table 3).

The numbering system of the ecological unit groups (Table 3) expresses a gradient from high position dry sites (group 1) to low position moist sites (group 6). Ecological land units have a two digit number, the first digit representing the ecological group and the second, the ecological unit within the group. Unit numbers were chosen so that similar units from the Brown County Hills and the Crawford Upland had the same number. The numbering system is patterned after the one being used for the Hiawatha National Forest in upper Michigan (E. Padley, personal communication).

Twelve ecological units for the Brown County Hills and 15 for the Crawford Upland (Table 3) were identified on the basis of the basic vegetation types such as dry or moderately dry, (Figure 4) and on the basis of the environmental variables associated with these divisions. For example, among the mesic slopes (group 5) of the Crawford Upland, unit 50 (Table 3) consists of sites that have a mesic vegetation type, generally face north of 315°- 135° azimuth, have a moderately deep mean A horizon (at least 6 cm), and an A-horizon pH which is on average greater than 5.2. Unit 51 meets all of the criteria for unit 50 but includes additional species typical of more moist situations, is restricted to northeasterly aspects, has an A horizon depth of greater than 10cm, and usually occurs low on the slope or in an otherwise sheltered location. Unit 52 also meets most of the criteria for unit 50 but also has limestone or calcareous rock layers, pH greater than 6.0 in some soil horizons, and calciphilic species such as chinkapin oak and *Jeffersonia diphylla.* Important identifying characteristics are summarized for each unit in Tables 4 and 5.

The most xeric ecosystems (units 10 and 20) usually occur on convex knobs and the ends of narrow ridges (unit 10) and on southwest-facing upper slopes (Table 4). Groundflora is low in diversity and usually dominated by *Vaccinium vacillans* and *Smilax rotundifolia. Carex picta* is usually abundant on these sites in the Brown County Hills, but is rare in the Crawford Upland. Soil A horizon is thin (usually <5cm) and soil pH is low (<5.0). The current overstory is usually dominated by chestnut oak and, less commonly, white oak.

The moderately dry ecosystems (units 11 and 21) are transitional between the dry and mesic sites (Tables 4 and 5, Figure 4). Although species typical of both dry sites and mesic sites may occur here, groundflora is generally dominated by species including *Parthenocissus quinquefolia, Galium circaezans,* and *Toxicodendron radicans* which have a wide ecological range and occur across many site types (Table 3). Slopes on unit 21 generally face south, 135-315°. Current overstory in stands older than 80 years is dominated by a mixture of upland oaks and hickories, but understory tree saplings may contain a strong component of sugar maple and beech.

The mesic ecological units (Figure 4) occur on northerly slopes, lower southerly slopes, on the sides of narrow ravines (unit 50), in a few narrow headwater bottoms (unit 60), and on broad, flat ridges (>75m wide) where they are usually associated with fragipan soils (unit 40). Groundflora contains mesic species including *Lindera benzoin* and *Arisaema triphyllum,* and several *Galium* species. With the exception of unit 40, mean soil A horizon depth is generally more than 6cm, and mean soil pH is generally greater than 5.0 (Table 4). Current overstory usually contains a strong maple-beech component as do the understory tree saplings. Mesic slopes, unit 50, is perhaps the most common ecological land unit on the landscape.

Moist-mesic sites (Figure 4) usually occur on the alluvial soils of narrow and medium sized bottoms of intermittent and perennial first to third order streams (unit 61). This vegetation type may also occur on protected northeast slopes on lower positions or benches in the Crawford Upland and locally on limestone slopes along Frog Pond Ridge in the Brown County Hills (unit 51). Soils are rich; A horizon depth is usually deeper than 9cm. The groundflora are lush and diverse. In addition to species typical of mesic sites, rich-site species such as *Asarum canadense* and *Cystopteris protrusa* are common. The overstory may contain species such as black walnut, American sycamore, American Basswood, and black cherry as well as a strong component of sugar maple and beech.

Floodplain sites (unit 62) occur on deep alluvial soils associated with the floodplains of larger, medium and low gradient streams and rivers (4th order and greater). These sites experience regular seasonal flooding. Groundflora is commonlydominated by waist-high thickets of wet-site

Table 4.—A summary of 15 ecological units for the Crawford Upland and Escarpment Sections. Summarized environmental variables include aspect, A horizon depth (A DEPTH), A horizon pH (A PH) B horizon soil texture (B TEXTURE), and slope position (POSITION). Ranges represent a 95 percent confidence interval for the mean. Soil texture includes the two most common textures observed for the unit.

Unit	Aspect	A Depth	A PH	B Texture	Position	Selected indicator species
10	None	3.2 ± 2.7	4.6 ± 0.6	SiL SiCL	Summit (narrow)	*Vaccinium vacillans, Panicum dichotomum* *Quercus prinus, Danthonia spicata*
11	None	3.8 ± 1.5	5.2 ± 0.2	SiL SiCL	Summit (narrow)	*Parthenocissus quinquefolia* *Galium circaezans*
12	None	2.2 ± 2.2	5.0 ± 0.4	SiCL SiC	Summit (narrow)	*Psoralia psoralioides* *Quercus stellata*
20	Southwest (180°-270°)	3.7 ± 0.8	4.7 ± 0.3	SiL SiCL	Backslope (Upper)	*Vaccinium vacillans, Panicum dichotomum* *Quercus prinus, Danthonia spicata*
21	South (135°-315°)	3.8 ± 1.8	5.0 ± 0.2	SiL SiCL	Backslope	*Parthenocissus quinquefolia* *Galium circaezans*
22	South (135°-315°)	2.2 ± 2.2	5.0 ± 0.4	SiCL SiC	Backslope	*Psoralia psoralioides* *Quercus stellata*
23	North (160°-290°)	2.7 ± 2.7	5.5 ± 0.4 (C-PH >6.2)	SiC C	Backslope	*Andropogon scoparius, Liatris spp* *Quercus stellata, Quercus marilandica*
30	Variable	3.5 ± 3.1	4.6 ± 0.4	LS SL	Cliff	*Hydrangea arborescens, Kalmia latifolia* *Medeola virginica, Dryopteris marginalis*
40	None	4.7 ± 1.2	5.5 ± 0.9	SiL SiCL	Summit (broad)	*Arisaema triphyllum, Osmorhiza claytoni* *Galium triflorum, Galium Concinnum*
50	North (315°-135°)	7.2 ± 1.0	5.4 ± 0.2	SiL SiCL	Backslope	*Arisaema triphyllum, Osmorhiza claytoni* *Galium triflorum, Galium Concinnum*
51	Northeast (350°-100°)	16.8 ± 2.2	5.6 ± 0.5	SiL SiCL	Backslope (Lower)	*Asarum canadense, Cystopteris protrusa* *Impatiens spp., Solidago flexicaulis*
52	Variable	8.3 ± 5.0	6.3 ± 0.3	SiCl	Backslope	*Quercus muhlenbergii, Jeffersonia diphylla* *Lithospermum latifolia*
60	None	7.7 ± 3.3	5.1 ± 0.9	SiL SiCL	Bottom (headwater)	*Arisaema triphyllum, Osmorhiza claytoni* *Galium triflorum, Galium concinnum*
61	None	11.8 ± 2.8	5.8 ± 0.4	SiL L	Bottom (minor)	*Asarum canadense, Cystopteris protrusa* *Impatiens spp., Solidago flexicaulis*
62	None	17.1 ± 5.6	6.8 ± 0.3	SiL L	Bottom (major)	*Boehmeria cylindrica, Laportea canadensis* *Acer saccharinum, Acer negundo*

Table 5.—A summary of 10 ecological units for the Brown County Hills Subsection of the Hoosier National Forest. Summarized environmental variables include aspect, A horizon depth (A DEPTH), A horizon pH (A PH) B horizon soil texture (B TEXTURE), and slope position (POSITION). Ranges represent a 95 percent confidence interval for the mean. Soil texture includes the two most common textures observed for the unit.

Unit	Aspect	A Depth	A PH	B Texture	Position	Selected indicator species
10	None	2.6 ± 1.4	4.6 ± 0.4	SiL SiCL	Summit (narrow)	*Vaccinium vacillans, Panicum dichotomum* *Quercus prinus, Danthonia spicata*
11	None	4.9 ± 2.0	5.0 ± 0.2	SiL SiCL	Summit (narrow)	*Parthenocissus quinquefolia* *Galium circaezans*
20	Southwest (180°-270°)	2.7 ± 0.7	4.6 ± 0.3	SiL SiCL	Backslope (Upper)	*Vaccinium vacillans, Panicum dichotomum* *Quercus prinus, Danthonia spicata*
21	South (135°-315°)	4.9 ± 1.6	4.9 ± 0.4	SiL SiCL	Backslope	*Parthenocissus quinquefolia* *Galium circaezans*
40	None	5.3 ± 2.7	5.2 ± 0.7	SiL SiCL	Summit (broad)	*Arisaema triphyllum, Osmorhiza claytoni* *Galium triflorum, Galium Concinnum*
41	None	6.2 ± 2.0	6.5 ± 0.4	SiCL C	Summit (karst)	*Arisaema triphyllum, Osmorhiza claytoni* *Galium triflorum, Quercus muhlenbergii*
50	North (315°-135°)	6.4 ± 1.1	5.3 ± 0.4	SiL SiCL	Backslope	*Arisaema triphyllum, Osmorhiza claytoni* *Galium triflorum, Galium Concinnum*
51	Northeast (350°-100°)	10.5 ± 1.6	6.6 ± 0.4	SiL SiCL	Backslope (Lower)	*Asarum canadense, Cystopteris protrusa* *Impatiens spp., Solidago flexicaulis*
60	None	7.5 ± 6.0	5.0 ± 0.1	SiL	Bottom (headwater)	*Arisaema triphyllum, Osmorhiza claytoni* *Galium triflorum, Galium concinnum*
61	None	12.7 ± 4.4	5.3 ± 0.4	SiL L	Bottom (minor)	*Asarum canadense, Cystopteris protrusa* *Impatiens spp., Solidago flexicaulis*
62	None	5.9 ± 2.3	6.1 ± 0.4	SiL L	Bottom (major)	*Boehmeria cylindrica, Laportea canadensis* *Acer saccharinum, Acer negundo*
63	None	6.7 ± 2.5	5.6 ± 0.3	SiL L	Bottom (major)	*Amphicarpa bracteata, Acer saccharum* *Boehmeria cylindrica, Laportea canadensis*

species including *Boehmeria cylindrica* and *Laportea canadensis.* Overstory dominants include silver maple, green ash, American sycamore, and boxelder. Tree seedlings and small shrubs are rare in many stands.

A transitional phase between ecological units 62 and 61 (unit 63, Table 3) was observed on two reference stands in the Brown County Hills. These stands occurred on major flood plains but on slightly higher elevations such as on small terraces and levies. Vegetation contained floodplain species, but also many moist-mesic and mesic species such as *Asarum canadense* and *Lindera benzoin.* The overstory contained sugar maple, beech, and lowland oaks such as pin oak as well as silver maple, boxelder, and sycamore (Table 5).

Dry clay sites (units 12, 22, and 23) occurred only in the southern portion of the Crawford Upland. Units 12 and 22 are transitional between the moderately dry ecosystems (units 11 and 21) and the true oak barrens (unit 23, Table 4). Barrens usually occur on southwest slopes on clay soils derived from shale. PH was commonly low (<5) on the surface horizons, but increased with depth to at least 6.0. Limestone fragments were occasionally observed on and in the soil. Stunted post oak and blackjack oak dominated the overstory. The barrens openings were dominated by prairie grasses and forbs including *Andropogon scoparius* and *Eryngium yuccifolium.*

Large sandstone cliffs (unit 30) were only observed in the Crawford Upland (Table 4). Soils, where present, were formed in sandstone, variable in depth, and sandy loam or loamy sand in texture. PH was on average <5.0. Mesic species occurred in the rich forest at the base of the cliffs. Species including *Hydrangea arborescens* and *Medeola virginica* were common on ledges, cracks, and seepage areas on the cliffs themselves. Dry species such as *Vaccinium vacillans* commonly occurred in the zone immediately above the cliffs. Mountain laurel (*Kalmia latifolia*) commonly occurred both in the cliff zone and in the upper dry zone. Overstory was dominated by red maple. Sugar maple, beech, tulip tree, and northern red oak were common in the lower mesic zone, while black oak, white oak, and chestnut oak were common in the upper, dry zone. Rare species including *Tsuga canadensis, Magnolia tripetala, Betula alleghaniensis,* and *Dodecatheon meadia* have also been observed associated with this ecological unit.

DISCUSSION

To the best of our knowledge, this system is the first multifactor ecological classification system proposed for the Central Hardwoods states. Previous efforts were essentially based on soils and physiography (Smalley 1979, 1980, 1984) or were from the Lake states, (Barnes et al. 1982, Hix 1988, Host 1987), or the Southeast (Van Lear and Jones 1987). The study most similar to this one was Fralish's integration of overstory composition with environmental variables including aspect, soil depth, and slope position on the Shawnee Hills National Forest in southern Illinois (Fralish 1988). However, ecological classification units derived from these relationships have yet to be published.

The Hoosier ECS has many similarities with other multifactor classifications in the eastern US, particularly in the importance of topographic position, aspect, and other variables associated with a soil moisture gradient in determining potential vegetation. A classification of 11 site units in the Kickapoo watershed in southwestern Wisconsin (Hix 1988), like the Hoosier system, separates gently sloping and ridgetop sites from steeply sloping sites. Aspect and soil parent material were important in distinguishing sloping-land ecosystems. As in the Hoosier, vegetation communities followed a moisture gradient from dry southwesterly slopes dominated by oaks and hickories to more mesic northeasterly slopes where there was a strong sugar maple component. Van Lear and Jones (1987) describe a system for the Savannah River Plant in South Carolina which is based on a gradient of topographic position and a corresponding moisture gradient ranging from xeric upland sands to wet poorly drained stream bottoms. Likewise, Barnes et al. (1982) describe an Upper Michigan classification based on a moisture gradient ranging from exposed rocky ridges to dry sandy flats to sloping lands to wetlands. Depth of soil to bedrock, soil drainage, and aspect on sloping sites are major indicators. None of these systems list soil A horizon depth, one of the main soil variables for the Hoosier ECS, as an indicator. However, A depth was important in a southern Indiana study relating the site index for black and white oak to environmental variables (Hannah 1968).

Although time and budgets did not permit us to use an independent dataset from each subsection of the forest to verify the correctness of the ecological unit classification, the Brown County Hills and Crawford Upland data sets represent independent sample data taken from landscapes with similar climate, geology, soils, and physiography. The fact that the vegetation classifications and indicator species for the two data sets were very similar and that aspect, slope position, A-horizon depth, and pH were the environmental factors most highly correlated with DECORANA scores in both cases (Table 2) provides a degree of verification for the classification.

Field testing indicated that the ECS field key (Figure 5) and the interrelationships on which it is based were generally successful identifying ecological units throughout both sections of the forest on the basis of their soils, vegetation, and physiography. When identifying units, we generally gave equal weight to the vegetation, soil, and physiographic components. Only rarely were conflicts observed between the ecosystem components while identifying units.

Field testing of ECS also revealed the strengths of a multifactor approach. While groundflora indicators generally remained common and identifiable on previously mature stands that had been selectively harvested or clearcut in recent decades, identification of units on the basis of indicators was often unsuccessful for heavily disturbed sites such as those which had been farmed, eroded, or planted to pine. Soil and physiographic indicators alone were used to classify such sites. On the other hand, variables not included in the ECS field key such as subsurface water flow could occasionally result in a vegetation type different from that expected on the basis of the known environmental factors. Since vegetation integrates site factors (Daubenmire 1980), a strong presence of indicator species and diagnostic species groups could be used to override soil and physiographic indicators in such cases. On mature sites near steady-state, vegetation can be used alone to classify ecosystems as in the habitat type approach (Jones 1989).

Many sites in the Hoosier have been severely disturbed and eroded. Since A horizon depth was strongly related to vegetation (Table 2), it is likely that eroded sites will not return to their original ecological potential for some time. The current potential for such sites is of interest. A mesic site (unit 40, or 50) for example, could be degraded to something resembling a moderately dry or dry site (ecological unit 21 or 20), or to something completely different. Since the vast majority of the broad flat ridges on the Hoosier National Forest were severely disturbed in the past, a degraded version of unit 40—unit 40L—was designated. Future refinements may describe degraded sites for other ecological units as well.

The Hoosier ECS is flexible. We expect that it will continue to evolve and be refined in response to the experience of managers, researchers, and others who use it. The current hierarchy and numbering system makes it easy to add, merge, or split units without disrupting the rest of the system. It would also be easy to add a classification of an adjacent Natural Region Section such as the Mitchel Karst plain without disrupting the hierarchy.

ECS will be useful as a management tool and could be helpful in developing silvicular recommendations. For example, Jones (1989) described a productivity continuum associated with ecological site units in South Carolina. Although the site indexes for key species for each Hoosier ecological unit have yet to be determined, differences in productivity most likely occur among these units. Moderately dry sites (units 11, 21) would probably be better sites for a silviculturalist to attempt to regenerate upland oaks than dry sites (units 10, 12, 20, 22, 23) where productivity is low, and mesic sites (units 40, 50, 51, 52) where productivity is high but competition with tolerant hardwoods such as sugar maple is severe.

ECS can also be used to identify potential rare species habitats. Rare species including *Betula alleghaniensis*, *Magnolia tripetala*, *Tsuga canadensis*, and *Dodecatheon meadia* are generally associated with sandstone cliffs (unit 30) when they occur. Yellowwood, *Cladrastis lutea*, is known from a few steep, northerly, mesic slopes (unit 50) in the Brown County Hills. Prairie grasses and forbes (the oak barrens community), a community of concern for the southern Crawford Upland, occurs on southwesterly slopes with clay soils where pH increases with depth (unit 43). Conservationists and managers attempting to locate, manage, or restore rare species such as these should look to these units as potential sites.

ECS can also serve as a research framework. Ecological units can be used to stratify the landscape ecologically into equivalent units that one can compare for different treatment groups. For example, one could evaluate the effects of potential overbrowsing by white-tailed deer in Brown County State Park where hunting is prohibited by comparing the groundflora composition of units within the park with the composition of the same ecological units outside the park where hunting is permitted.

In the future, verification and refinement of the system and the field key will continue. Productivity differences among ecological units will also be studied. Mapping of ecological units across the landscape of the Hoosier National Forest is the next major step in the development of this ECS. Mapping will function as a form of "operational verification" of the system; verifying that these units can indeed be mapped in terms of the vegetation, physiography, and soils relationships we have described. Mapping forms the heart of classification (Barnes et al. 1982) and will provide a basis for regional landscape planning and ecosystem management. Moreover, a map of ecological land units is the first step in developing management units that are also ecological units.

A decade ago, Barnes et al. (1982) stated that multifactor ecological classification had arrived in Europe and Canada and predicted that it would come to the US. It has now reached theCentral Hardwoods region. Because of the increasing need to understand the ecosystems we manage, demand for such systems and for an understanding of the basic vegetation-soil-physiography interrelationships of ecosystems will continue to increase. This study, as one of the first efforts, can therefore serve as a model for others in this region.

LITERATURE CITED

Alexander, R.R., G.R. Hoffman, and J.M. Wirsing, 1986. Forest vegetation of the Medicine Bow National Forest in southeastern Wyoming: a habitat type classification. USDA Forest Service Research Paper RM- 271.

Bailey, R.G. 1989. Ecoregions of the Continents. Map. USDA Forest Service, Washington DC.

Barnes, B.V., K.S. Pregitzer, T.A. Spies, and V.H. Spooner. 1982. Ecological forest site classification. J. For 80(8):493-498.

Beers, T.W. and P.E. Dress. 1966. Aspect transformation in site productivity research. J. For., 64:691-692.

Cajander, A.K., 1926. The theory of forest types. Acta. For. Fenn. 29(3):1-108.

Clark, F.B. 1989. The central hardwood forest. USDA Forest Service, Central Hardwoods Note 1.01. North Central Forest Experiment Station, St. Paul, Minn.

Coffman, M.S. and G.L. Willis. 1977. The use of indicator species to classify climax sugar maple and eastern hemlock forests in Upper Michigan. Forest Ecol. and Mgt. 1:149-168.

Coffman, M.S., E. Alayanak, and R. Resovsky. 1980 Habitat classification system field guide: northern Lake States region. Cranbrook Institute of Science. 100 p.

Cooper S.V., K.E. Neiman, R. Steele, and D.W. Roberts. 1987. Forest habitat types of northern Idaho: a second approximation. USDA Forest Service General Technical Report INT-236. 135 p.

Daubenmire, R. 1980. The scientific basis for a classification system in land use allocation. P. 7-10 in The scientific and Technical basis for land classification: a Joint Technical Session. Soc. Am. For. Annu. Conv., Oct 7, 1980, Spokane, WA.

Daubenmire, R. and J.B. Daubenmire. 1968. Forest vegetation of eastern Washington and northern Idaho. Washington Agricultural Experimental Station, Washington State University. Technical bulletin 60. 104 p.

Fralish, J.S. 1988. Predicting potential stand composition from site characteristics in the Shawnee Hills forest of Illinois. Amer. Mid. Nat. 120:79-101.

Gauch, H.G. Jr. 1982. Multivariate analysis in community ecology. New York, Cambridge University Press. 298 pp.

Hannah, P. R. 1968. Topography and soil relations for white and black oak in southern Indiana. USDA For. Serv. Res. Pap. NC- 25. 7p.

Hill, M.O. 1979a. DECORANA-a FORTRAN program for detrended correspondence analysis and reciprocal averaging. Ecology and systematics, Cornell University, Ithica, NY. 52 p.

Hill, M.O. 1979b. TWINSPAN- a FORTRAN program for arranging multivariate data in an ordered two-way table by classification of the individuals and attributes. Ecology and systematics, Cornell University, Ithica, NY. 90 p.

Hintze, J.L. 1990. Number cruncher statistical system version 5.03: installation and reference manual. Kaysville, Utah.

Hix, D.M. 1988. Multifactor classification and analysis of upland hardwood forest ecosystems of the Kickapoo River watershed, south western Wisconsin. Can. J. For. Res. 18:1405-1415.

Homoya, M.A., D.B. Abrell, J.R. Aldrich and T.R. Post. 1984. The natural regions of Indiana. Indiana Acad. Sci. 94:245-268.

Parker, G.R., 1989. Old growth forests in the central hardwoods region. Natural Areas Journel. 9(1):5-11.

Host, G.E. 1987. Spatial patterns of forest composition, successional pathways and biomass production among ecosystems of northwestern lower Michigan. Ph.D. thesis, Michigan state University, East Lansing, MI. 203 p.

Jones, S.M. 1989. Application of landscape ecosystem classification within the southeastern United States. P. 79-83 in proc. soc. am. for. national convention. Spokane, Washington.

Jordan, J.K. 1982. Application of an integrated land classification. P. 65-82 in G.D. Mroz, ed. Artificial regeneration of conifers in the upper Great Lakes region. Michigan Technological University, Houghton, Michigan. 435 p.

Ludwig, J.A. and J.F. Reynolds. 1988. Statistical ecology. Wiley, New York. 337 p.

Pfister, R.D. 1977. Ecological classification of forest land in Idaho and Montana. P. 329-357 in Proc. Ecological classification of forest land in Canada and northwestern USA. University of British Columbia, Vancouver.

Pfister, R.D. and S. Arno. 1980. Classifying Forest habitat types based on climax vegetation. For. Sci. 26(1):52-70.

Pregitzer, K.S. and B.V. Barnes. 1984. Classification and comparison of upland hardwood and conifer ecosystems of the Cyrus H. Mccormick experimental forest, USA. Can. J. For. Res. 14(3):362-375.

Smalley, Glendon W. 1979. Classification of forest sites on the on the southern Cumberland Plateau. USDA Forest Service General Technical Report, SO-23. 59 p.

Smalley, Glendon W., 1980. Classification and evaluation offorest sites on the western Highland Rim and Pennyroyal. USDA Forest Service General Technical Report. SO-30. 120 p.

Smalley, G.W. 1984. Land forms: a practical basis for classifying forest sites in the interior uplands. P. 92-112 in 12th annual hardwood symposium, Hardwood Research Council, May 8-11, 1984, cashiers, NC.

Spies, T.A. and B. V. Barnes. 1985. A multifactor classification of the northern hardwood and conifer ecosystems of the Sylvania Recreation Area, Upper Peninsula, Michigan. Can J. For. Res. 15:949-960.

Van Lear, D.H. and S.M. Jones. 1987. An example of site classification in the southeastern coastal plain based on vegetation and land type. SJAF 11:23-28.

ACKNOWLEDGEMENTS

The authors acknowledge the USDA Forest Service for funding this work and for helping with stand selection and navigation. They also thank the summer field crews: Cindy Heubner, Bill Rude, Steve Ross, Sally Weeks, Tom Adams, Gary New, Shane McBurnette, Larry Beard, Esther Schnieder, Esther Hendrickson, Jim Chattin, Carl Schmidt, and Jean Van Kley. Special thanks to Dr. D.P. Franzmier, Dr. A. Gilesipie, and Dr. J.C. Randolph who, as a graduate committee, critiqued and guided this work. Thanks also to Bob Balentyne, Pat Merchant, Wanda Iza, Steve Olsen, and Mike Homoya for their involvement in this project.

A Comparison of Forest Dynamics at Two Sites in the Southeastern Ozark Mountains of Missouri

Michael A. Jenkins and Stephen G. Pallardy[1]

Abstract: Changes in tree species composition and regeneration patterns were studied in 53 permanent vegetation plots located at two sites (Pioneer Forest and University State Forest) in oak-hickory forests of southeastern Missouri where mortality and decline of red oak species have been identified. The two sites also exhibited differing levels of decline and mortality. Between 1962 and 1991 the importance value (IV) of white oak at University State Forest increased from 20 to 56%, while that of black oak and, to a lesser degree, scarlet oak decreased. Over the same 28 year period, the IV of white oak at Pioneer Forest increased from 36 to 49%, but the importance of black oak remained constant, and the importance value of scarlet oak decreased only slightly. Sapling densities of the red oak species group (black oak, scarlet oak, and southern red oak) ranged from 2-43/ha at University State Forest and from 0 to 30/ha at Pioneer Forest. These densities were low when compared to those of the corresponding white oak species group (white oak and post oak) sapling densities for University State Forest (16-51/ha) and Pioneer Forest (0-148/ha). Recent recruitment does suggest, however, that red oak group species will have a continued importance in these forests; the densities of black oak and scarlet oak seedlings (880-1665/ha at University State Forest and 408-1167/ha at Pioneer Forest) were comparable to those of post oak and white oak (1187-1474/ha at University State Forest and 233-2625/ha at Pioneer Forest).

INTRODUCTION

Since 1980 a considerable increase in red oak group mortality has been observed in the Ozark Mountains of southeastern Missouri (Johnson and Law 1989). As a result, over 35 million board feet of dead and dying oak timber was harvested in salvage sales on the Mark Twain National Forest between 1980 and 1986 (Law and Gott 1988). In addition, there has been much discussion about which management methods best ensure oak regeneration in Ozark forest stands (Sander 1983).

The history of the Ozark region is one of disturbance. Early Native Americans are believed to have shaped the early Ozarks into an open mosaic of forest types through the use of fire (Buckner 1989, Guyette and Cutter 1991). After settlement and the removal of the indigenous people, fire frequency was greatly reduced and the forests of the region became less open (Beilmann and Brenner 1951). The majority of this forest was pine or oak-pine in composition, with *Pinus echinata* Mill. (shortleaf pine) dominating upper slopes and ridges and *Quercus alba* L. (white oak) dominating lower slopes (Cunningham and Hauser 1989).

At the turn of the century large lumber companies logged huge portions of the forest, ultimately removing 1.5 billion board feet of lumber (Schuchard and Kohler 1984). The major focus of this logging was *Pinus echinata* (shortleaf pine), but oak was also cut for use in flooring, barrel staves, and rail road ties (Hill 1949). Of the oak species, *Quercus alba* was the most heavily harvested

---

[1] School of Natural Resources, University of Missouri-Columbia, Columbia, MO 65211.

(Hill 1949). This large scale harvest greatly reduced the importance of *Pinus echinata* in the region and allowed the establishment of red oak group species on sites formerly dominated by *Pinus echinata* (Law and Gott 1987).

Over the past two decades much concern has been expressed about oak stands not being replaced by new oak stands after harvest in oak-hickory forests (Loftis 1983). Oak regeneration success is usually dependent upon some sort of disturbance which allows greater light intensities to reach shade intolerant oak seedlings. Stands that have been thinned, or lightly burned generally possess a greater reservoir of oak regeneration that stands that have been left undisturbed (Carvell 1979). In traditionally managed stands, clear-cutting and shelterwood methods often are used to produce higher light intensities to encourage oak regeneration (Johnson 1982).

One can hypothesize that while past disturbances and land use practices have created fairly homogeneous, even-aged stands across much of the Ozark Mountain region, the effect of this phenomenon on species composition and regeneration may vary with differing management strategies. Certain management strategies may serve to decrease the negative effects of oak decline and mortality while improving regeneration. This study compared the vegetation dynamics of 53 permanent plots located at two sites (University State Forest and Pioneer Forest) in southeastern Missouri in which mortality and decline of red oak species have been identified. The permanent plots at University State Forest have essentially been unmanaged since the large scale timber harvest at the turn of the century (J. Dwyer, School of Natural Resources, University of Missouri, personal communication). The permanent plots at Pioneer Forest have been managed through selective cutting and thinning since the 1950's (C. Trammel, Pioneer Forest, personal communication). By comparing the permanent plots at these two sites, a comparison of differences in vegetation composition through time and regeneration was made.

MATERIALS AND METHODS

Two approaches were employed to accomplish study objectives. First, a characterization of mortality present in the Ozark Region and the resulting changes in vegetational composition were completed through the sampling of permanent continuous forest inventory (CFI) plots at University State Forest and Pioneer Forest. In addition, regeneration was determined through the measurement of seedling and sapling densities on these plots. Sampling was completed during the summers of 1990 and 1991 at University State Forest and Pioneer Forest, respectively.

Study Sites

University State Forest

University State Forest is located in Wayne and Butler Counties approximately 16 km north of Poplar Bluff (36° 55' N, 90° 15' W) on the southeastern edge of the Missouri Ozarks. University State Forest has a less rugged topography than is found to the north and northwest. Broad and narrow ridges are common, giving way to steep or gentle side slopes with frequent rock outcrops along major streams and drainages (Nigh 1984). Fragipans are often present on broad level ridgetops, with side slopes displaying varying amounts of chert (Graves 1983).

Pioneer Forest

Pioneer Forest is a large (62,889 ha), privately-owned tract of forested land located in 7 counties of the eastern Ozark Mountains. Stands occupy a wide range of topography, ranging from steep rugged slopes and dissected ridges to gentle slopes and plateaus. CFI plots sampled at Pioneer Forest were located throughout Dent, Shannon, and Reynolds Counties. These three counties contained the best range of red oak species group mortality on Pioneer Forest. CFI plots in this research had experienced light disturbance through selective cutting and understory thinning (C. Trammel, personal communication).

Selection of CFI plots

Individually, plots were selected to offer a broad representation of the varying degrees of oak decline present in each study site. For the purpose of this study, decline and mortality were synonymous. The past data from the CFI plots made this comparison of mortality between plots possible. Although a wide diversity of decline levels was the primary criterion for the selection, plots also were selected to provide an ample representation of the micro-environmental conditions (topography, soil, etc.) present at each study site. Plots exhibiting heavy or recent logging, extremely low basal area and/or extensive management were eliminated from consideration for sampling.

Vegetation Sampling

The CFI plot trees at University State Forest and Pioneer Forest have been measured every five years between 1962 and 1987. Vegetation sampling for this project was completed during the summers of 1990 and 1991. Once a plot was selected, the sampling strategy consisted of two parts: (1) remeasurement of previously established permanent plots, and (2) additional sampling of seedling and sapling layers, which were not included in the permanent plot databases. On each plot dbh of the previously censused and ingrowth trees was measured. In addition, a concentric one-tenth acre (0.04 ha) circular plot was inventoried for the total number of saplings (stems ≥ 1 m in height) by species, and four one-thousandth acre (0.00004) circular plots were surveyed for seedling density. These four seedling plots were placed random at distances north, south east, and west from plot center. Thirty-two permanent plots at University State Forest and 21 permanent plots at Pioneer Forest were sampled.

Data Preparation and Analysis

Density (stems/ha), basal area (m^2/ha), and importance value (IV = relative density [species density/total density] + relative basal area [species basal area/total basal area]) were calculated for each remeasurement of the CFI plots. In addition, the density of seedlings and saplings was calculated for each plot.

Quercus velutina and *Q. coccinea* mortality was then quantified. This was accomplished by using CFI plot data to calculate the percent mortality for each remeasurement interval. These intervals were: 1962-1967, 1967-1972, 1972-1977, 1977-1982, 1982-1987, and 1987-1990 (University State Forest) and 1991 (Pioneer Forest). The number of trees that died in an interval was divided by the number of trees living in 1962. Since the sampling of the CFI plots was a 100% census, it was unnecessary to test changes in species mortality, basal area, density, or importance within a site for significance.

RESULTS

Analysis of the mortality of living trees from the 1962 measurement revealed different mortality rates and patterns between University State Forest and Pioneer Forest (Figure 1). University State

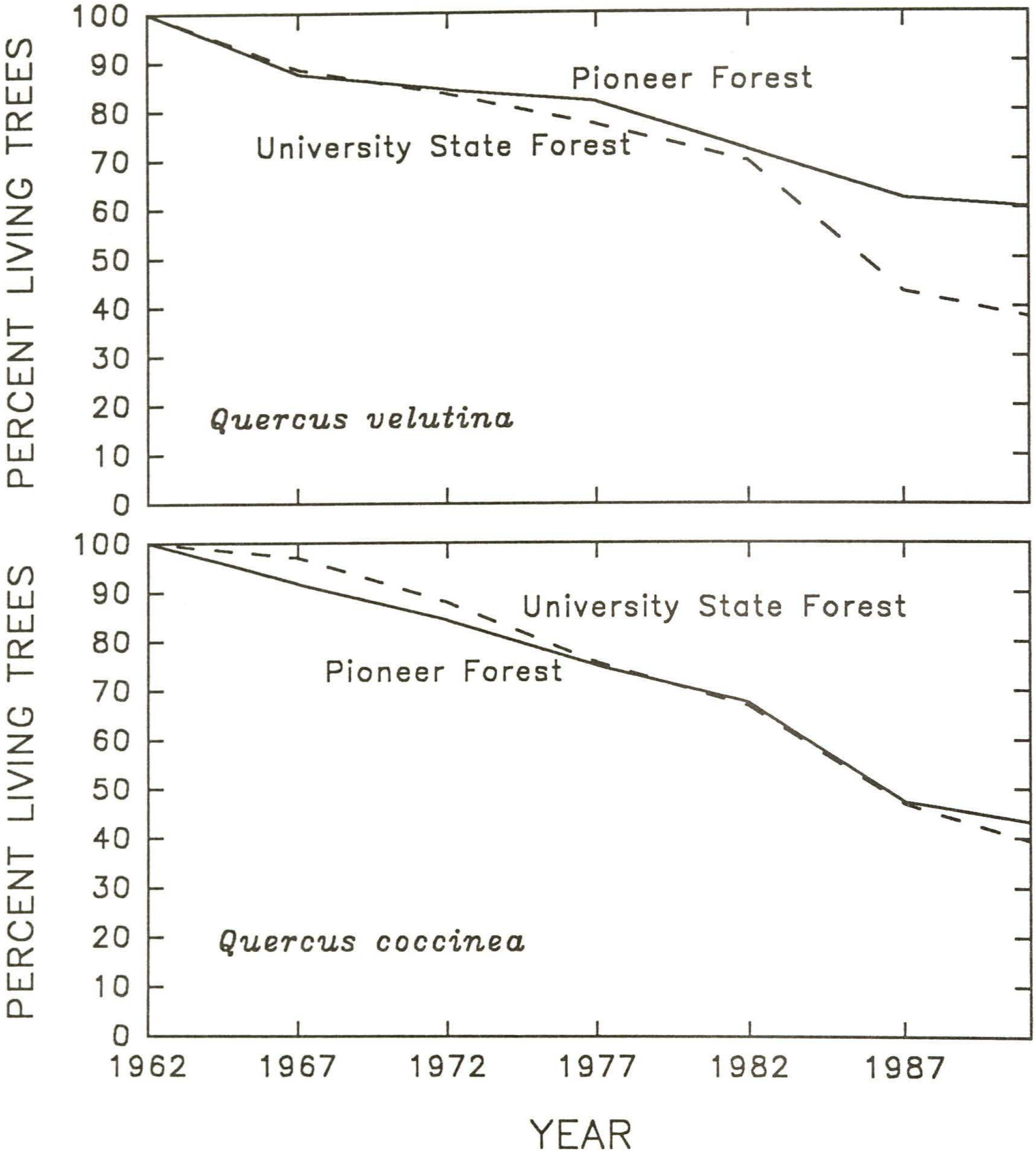


Figure 1.—Comparison of the mortality of *Quercus velutina* and *Q. coccinea* trees which were living at University State Forest and Pioneer Forest in 1962. Plot represents percent of original trees living at each remeasurement.

Forest sustained much greater relative mortality of the original *Quercus velutina* living trees than did Pioneer Forest. Only 38% of the *Q. velutina* trees originally measured at University State Forest in 1962 were still living in 1991, compared to 60% for Pioneer Forest. The mortality rate of *Q. velutina* at University State Forest mirrored that at Pioneer Forest until the 1982 remeasurement, but between 1982 and 1990 the mortality rate of this species at University State Forest was significantly greater ($p = 0.05$) then at Pioneer Forest. The two sites showed no significant differences in the mortality of *Q. coccinea* trees from the 1962 measurement. Approximately 40% of the *Q. coccinea* trees measured in 1962 were still living in 1991 at both sites.

Analysis of IV over the 29-year period revealed several changes in the species composition of both sites (Figure 2). The IV of *Quercus velutina* showed a sharp decrease at University State Forest since the 1982 measurement, but no such decrease was apparent at Pioneer Forest. At both sites there was a slight decrease in the IV of *Q. coccinea*. Significantly, there was an increase in *Q. alba* IV at both sites. This increase was more notable at University State Forest, which showed a sharp increase in *Q. alba* IV after 1982, corresponding to the drop in *Q. velutina* IV over the same time period.

These different trends in oak species composition can be better explained by examining changes in basal area, density, relative basal area, and relative density (Figures 3-6). At University State Forest there were sharp declines in both mean plot basal area and mean plot density of *Quercus velutina* following the 1982 remeasurement, with mean density also declining steadily before 1982. This trend held true when relative basal area and relative density of *Q. velutina* were considered, but the declines were not as steep nor as sudden. Pioneer Forest experienced no such declines in *Q. velutina* mean density, and a small but steady increase in mean basal area. The relative density and relative basal area of *Q. velutina* at Pioneer Forest exhibited similar trends.

As previously stated, the decline in *Q. coccinea* IV was slight at both sites. The mean density of *Q. coccinea* has declined steadily at University State Forest since 1967, but the rate of decline increased after 1982. There also was a decrease in mean *Q. coccinea* basal area following 1982, after a steady increase since 1962.

Consideration of *Q. coccinea* relative basal area and relative density at University State Forest revealed that these declines in basal area and density were not as severe when compared to the basal area and density of all species. A decline in *Q. coccinea* relative density was evident, but the extent was considerably less than was suggested by absolute density. In addition, there was little if any discernible decrease in *Q. coccinea* relative basal area. These findings suggest that the decline in *Q. coccinea* density is being compensated by an increase in the basal area of living trees.

Pioneer Forest has experienced only a slight decease in *Quercus coccinea* mean density since 1982, and has experienced an increase in *Q. coccinea* mean basal area over the same time period. In addition, no discernible changes in relative density or relative basal area have occurred since 1982, and only a slight overall decrease has occurred since 1962. *Quercus alba* appears to be only one of the dominant canopy species increasing in importance at both sites. The large increase in mean density, combined with a slight increase in mean basal area, suggest that this increased importance is due to an increase in smaller *Q. alba* trees. This trend is supported by the relative density and relative basal area of *Q. alba* at both study sites. At University State Forest a rapid increase in relative density of *Q. alba* is evident following the 1982 remeasurement. An increase in relative basal area after 1982 also was evident, but the magnitude of increase was reduced in comparison to that of relative density. Pioneer Forest also experienced an increase in *Q. alba* relative basal area and relative density.

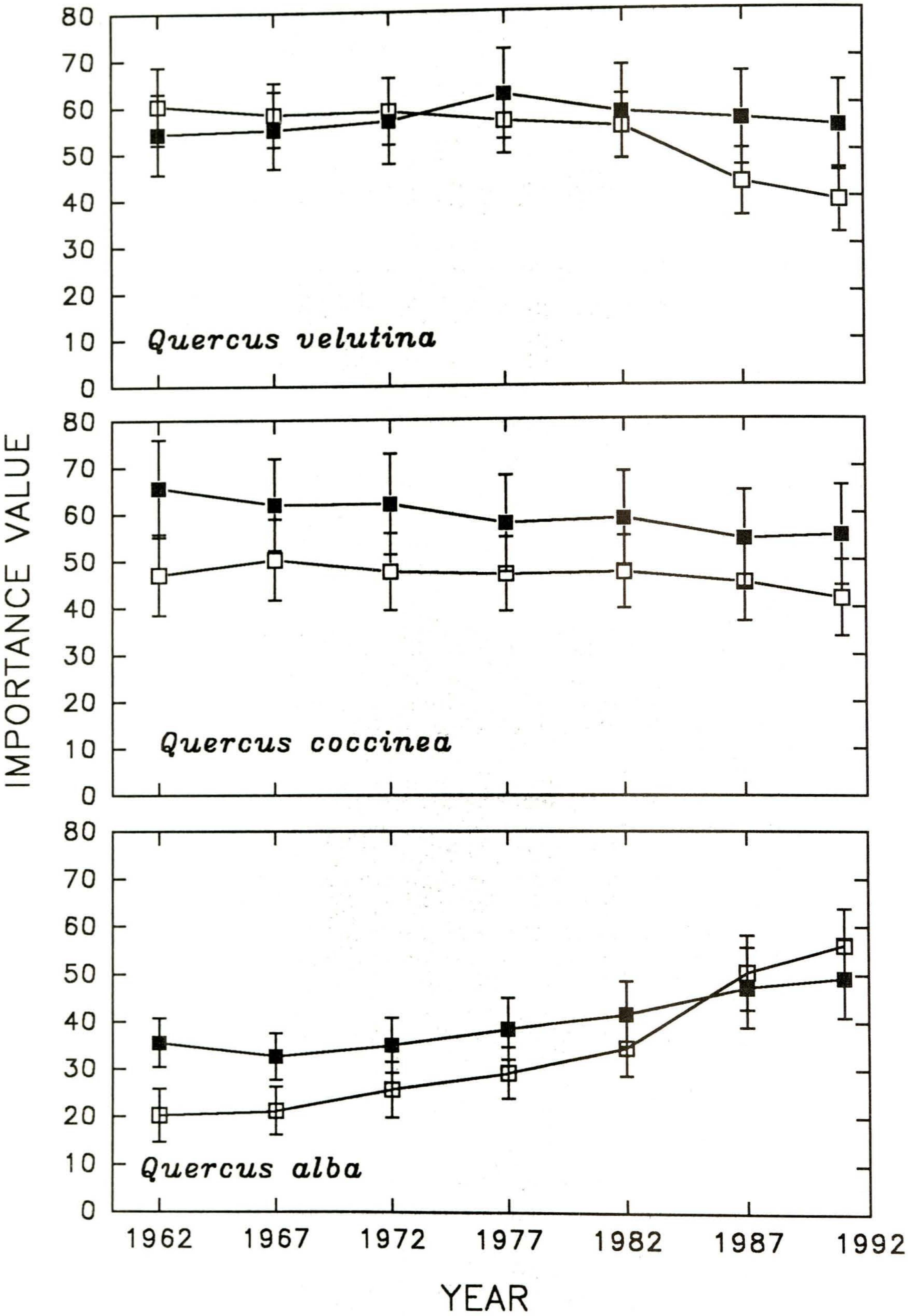


Figure 2.—Comparison of importance value of major *Quercus* species at University State Forest and Pioneer Forest between 1962 and 1991. Bars represent ± 1 S.E.

□ University State Forest
■ Pioneer Forest

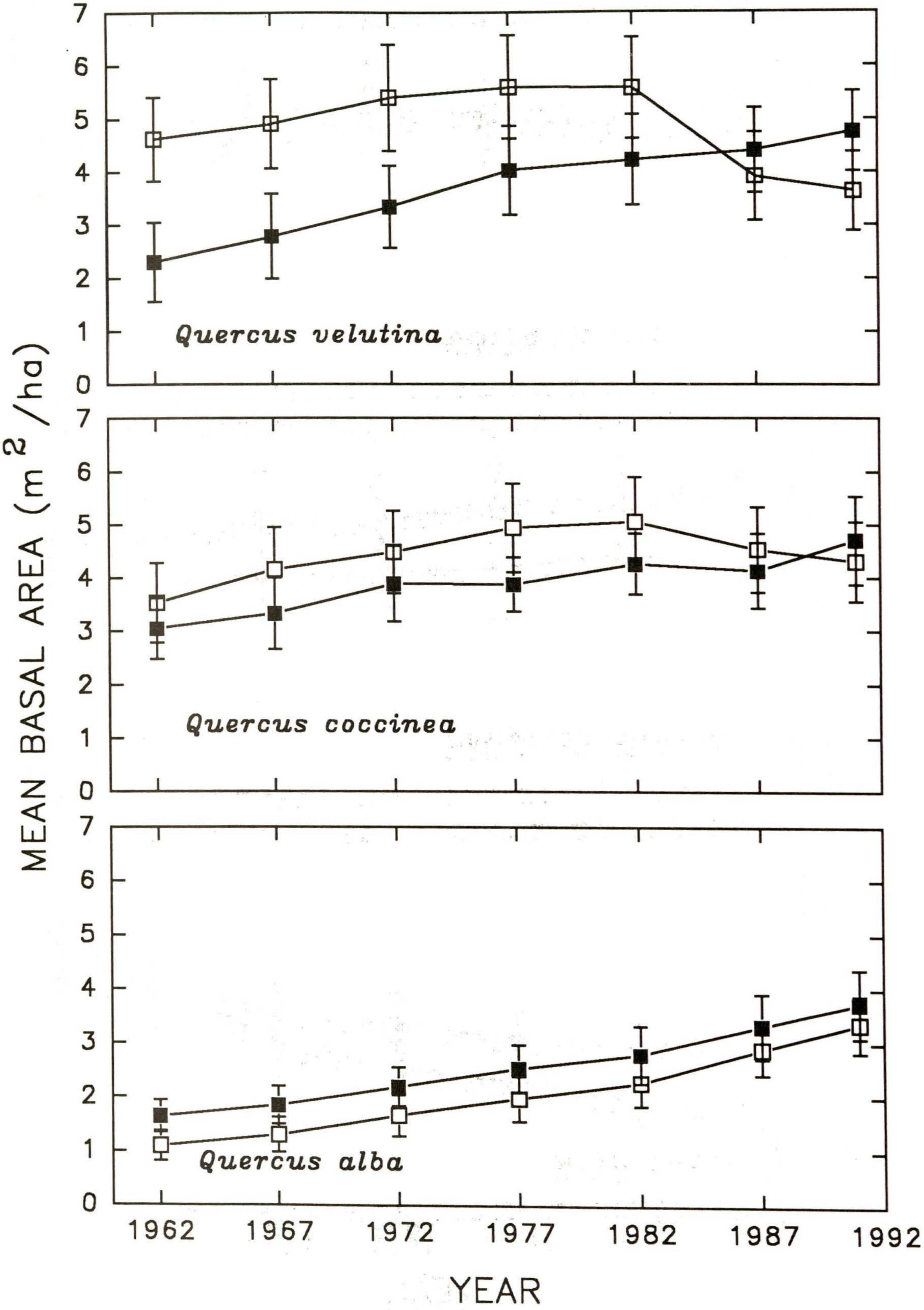


Figure 3.—Comparison of mean plot basal area of major *Quercus* species at University State Forest and Pioneer Forest between 1962 and 1991. Bars represent ± 1 S.E.

□ University State Forest

■ Pioneer Forest

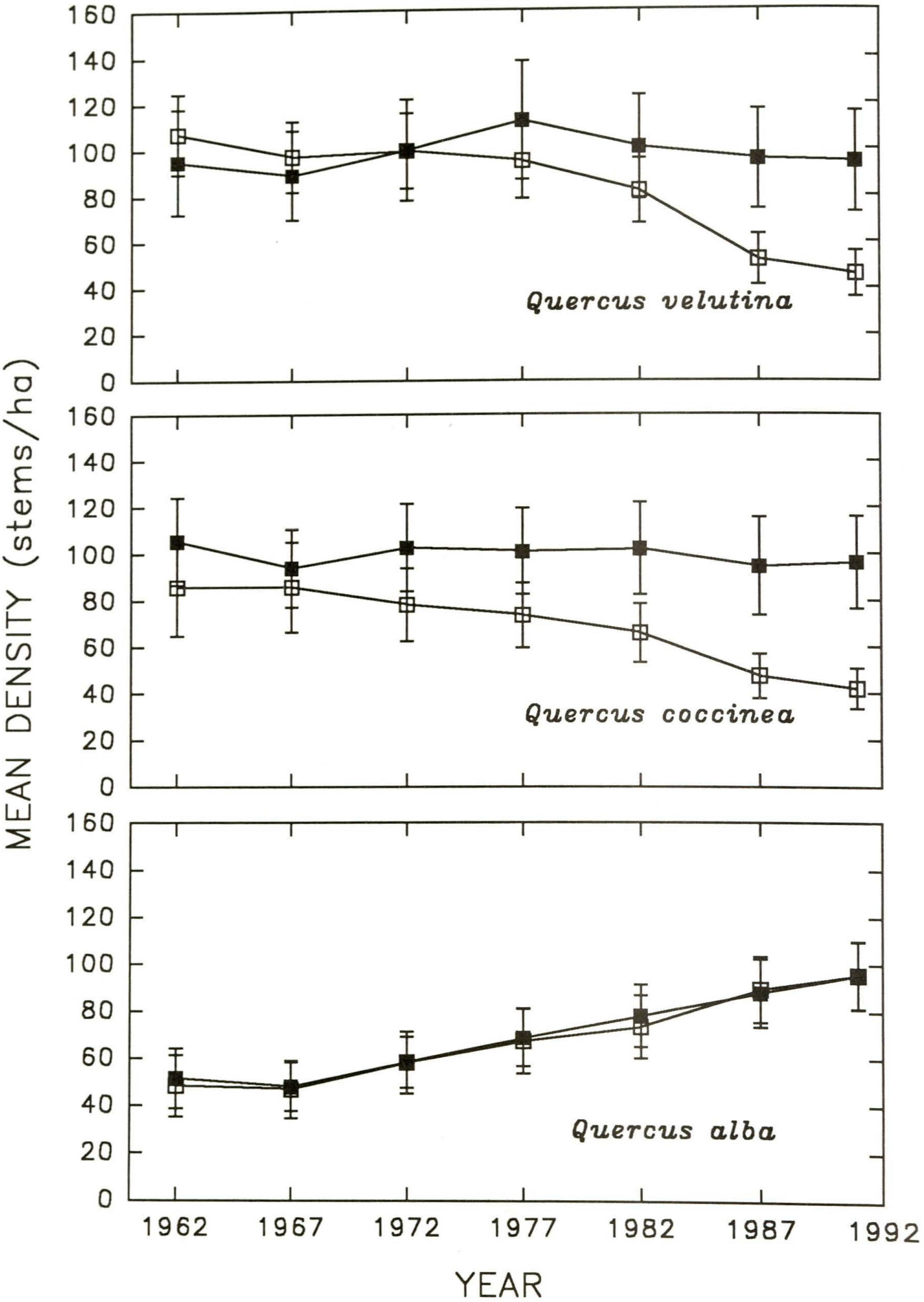


Figure 4.—Comparison of mean plot density of major *Quercus* species at University State Forest and Pioneer Forest between 1962 and 1991. Bars represent ± 1 S.E.

□ University State Forest
■ Pioneer Forest

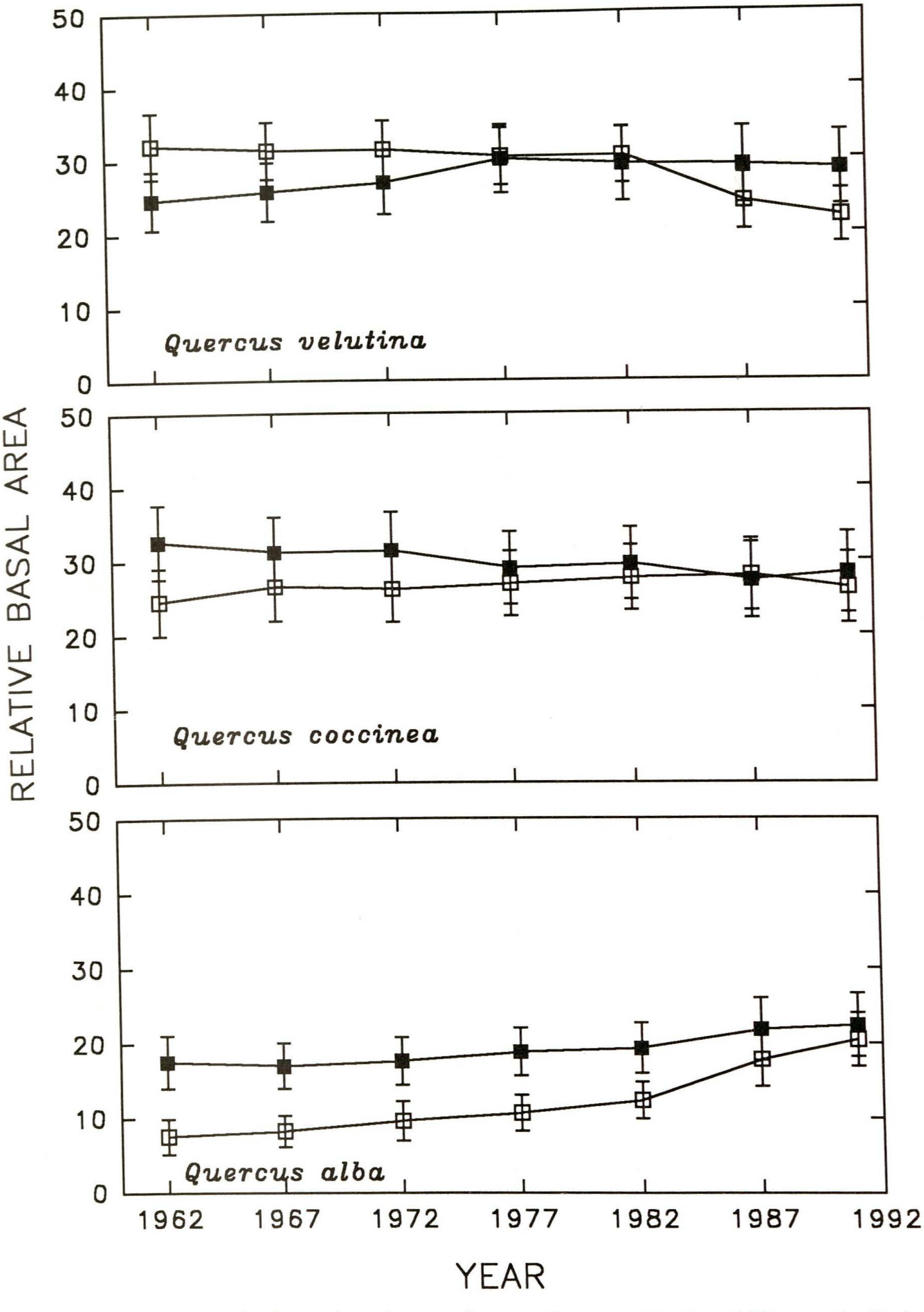


Figure 5.—Comparison of relative basal area of major *Quercus* species at University State Forest and Pioneer Forest between 1962 and 1991. Bars represent ± 1 S.E.

☐ University State Forest
■ Pioneer Forest

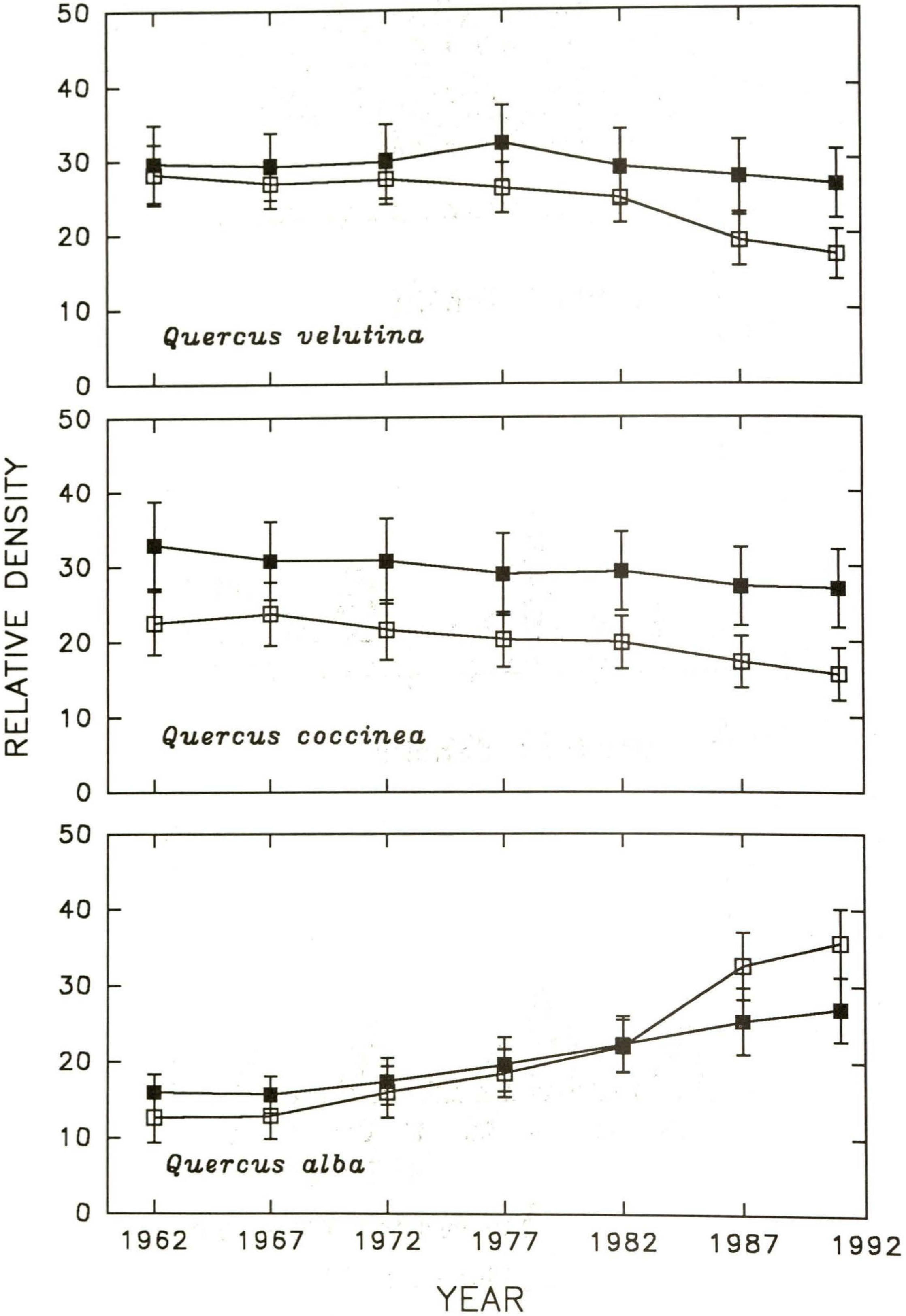


Figure 6.—Comparison of relative density of major *Quercus* species at University State Forest and Pioneer Forest between 1962 and 1991. Bars represent ± 1 S.E.

- □ University State Forest
- ■ Pioneer Forest

The dominance of red oak group species observed in the canopy stratum of the two sites was not evident in the sapling layer (Figure 7). Across both sites *Quercus coccinea* sapling densities were significantly lower (p = 0.05) then those of *Quercus alba*. The sapling densities of *Quercus velutina* across the two sites were also lower then those of *Q. alba*, but the differences were not significant. Overall, *Cornus florida* was the dominant sapling layer species across the study sites (254 stems/ha), followed by *Sassafras albidum* (106 stems/ha), *Carya texana* (98 stems/ha), *Nyssa sylvatica* (83 stems/ha), and *Q. alba* (80 stems/ha), respectively.

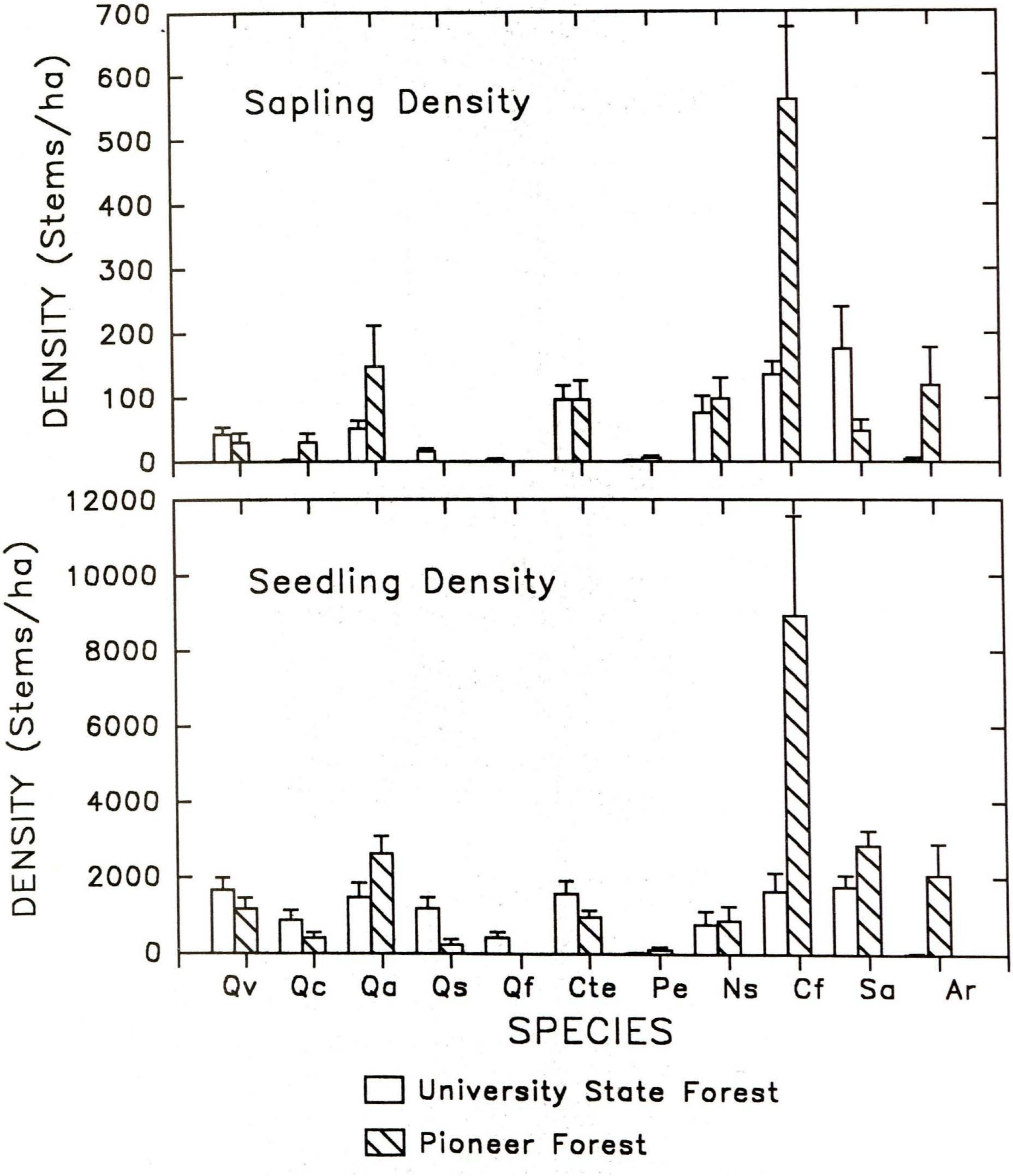


Figure 7.—Mean sapling and seedling densities for the 0.08 ha plots. Bars represent ± 1 S.E.
Qv = *Quercus velutina*, Qc = *Q. coccinea*, Qa = *Q. alba*
Qs = *Q. stellata*, Qf = *Q. falcata*, Ct = *Carya texana*,
Pe = *Pinus echinata*, Ns = *Nyssa sylvatica*, Cf = *Cornus florida*, Sa = *Sassafras albidum*, Ar = *Acer rubrum*.

Analysis of sapling densities by site suggested differences in sapling layer composition between study sites (Figure 7). Pioneer Forest appeared to have a greater density of *Q. alba* saplings than University State Forest. Pioneer Forest had a significantly greater ($p = 0.05$) *Q. coccinea* sapling density than University State Forest. Although University State Forest had the higher *Q. velutina* sapling density, the difference between sites was not significant. Pioneer Forest had a significantly greater ($p \leq 0.01$) *Cornus florida* sapling density than the other two sites. Dominance of *Cornus florida* in the sapling and seedling layers was stated as a management problem in some Pioneer Forest stands (C. Trammel, personal communication).

The three study sites exhibited differing seedling densities for the major seedling layer species. Pioneer Forest exhibited a significantly higher ($p = 0.05$) *Quercus alba* seedling density than University State Forest. Plots of the two study sites exhibited no significant differences in *Q. velutina* seedling density. The *Quercus stellata* density at University State Forest was significantly greater ($p = 0.05$) than that of Pioneer Forest. The three sites also differed in the seedling densities of non-oak species. Pioneer Forest's *Cornus florida* seedling density was significantly greater ($p= 0.01$) than that of University State Forest. This high seedling density, combined with the high *C. florida* sapling density, indicated that this species is dominant in the Pioneer Forest understory.

DISCUSSION

Differences in vegetational composition and temporal trends were evident between the two study sites. University State Forest and Pioneer Forest exhibited similar *Quercus coccinea* mortality, but University State Forest exhibited much greater *Q. velutina* mortality. In addition, changes in IV between 1962 and 1991 suggest that, with regard to vegetation composition, the two sites are moving in different directions. University State Forest has experienced a decline in *Q. velutina* IV since 1980, while the IV of this species at Pioneer Forest has remained stable. Both University State Forest and Pioneer Forest showed a slight decrease in *Q. coccinea* IV between 1980 and 1987, but after this period the IV of *Q. coccinea* at Pioneer Forest increased, while at University State Forest importance of this species continued its gradual decline. At both sites there has been an increase in *Q. alba* IV, but at Pioneer Forest the rate of increase has been constant since 1967 while at University State Forest *Q. alba* IV has increased dramatically since 1982.

This large scale cutting of timber over a relatively short period resulted in mostly even-aged stands at both sites. The even-aged nature of these stands has possibly increased the importance of cohort senescence in the region. According to Mueller-Dombois (1988), a forest that consists of a mosaic of even-aged stands, stand segments in advanced age states, or senescing cohort stands can be expected to die more or less synchronously, when an environmental or biotic trigger is provided. In Missouri, drought appears to have been this trigger (Law and Gott 1987, Jenkins 1992). While cohort senescence has been described as a natural phenomenon (Mueller-Dombois 1987), the previous land use practices in the Ozarks may have abnormally enhanced its probability and produced a predisposition to large scale oak decline and mortality.

Differences in the management of the two sites may in part explain their differences in forest composition and red oak group mortality resulting. The stands in which permanent plots were studied at University State Forest have been essentially unmanaged since they were first harvested at the turn of the century. Pioneer Forest (including the CFI plots), however, has been managed through the use of selective cutting and thinning. Thinning is conducted in immature stands to reduce competition as the stand matures. When enough trees within a stand are of sufficient size for harvest, these larger trees are selectively cut. The cutting of these trees may explain the lower *Quercus velutina* mortality at Pioneer Forest. The observed reduction in natural mortality of this species may be because of harvesting of the larger trees before they die. When mortality at Pioneer Forest resulting from selective cutting and thining was combined with that resulting from natural causes, University State Forest still exhibited significantly greater ($p = 0.05$) mortality after 1982.

However, the difference in mortality between the two sites was greatly reduced. In addition, the harvesting of these larger, slower-growing trees may allow the younger, faster-growing trees to grow with reduced competition for light, water and nutrients. This increased availability of light may also explain why Pioneer Forest has shown no major decrease in the density of *Q. velutina* and *Q. coccinea*, two species that are considered shade intolerant (Hinckley et al. 1979). Finally, the selective cutting employed at Pioneer Forest may be creating more uneven aged stands, which would therefore be less susceptible to synchronous mortality associated with cohort senescence as described by Mueller-Dombois (1987).

Selective cutting has long been criticized for not allowing sufficient oak regeneration (Sander and Clark 1971). However, the results of this study indicate that oak regeneration on Pioneer Forest is certainly comparable, and perhaps superior, to that of University State Forest. *Quercus velutina* and *Q. coccinea* seedling densities were not significantly different on the two sites. Pioneer Forest, however, did have a significantly greater density of *Q. alba* seedlings. In addition, Pioneer Forest had significantly greater *Q. coccinea* and *Q. alba* sapling densities than did University State Forest. These results suggest that uneven-aged management of oak-hickory forests in the Ozarks might provide sufficient regeneration to perpetuate oak species in subsequent stands.

While the two sites have exhibited different trends in mortality, vegetational composition, and regeneration, there are several overall trends that are evident at both sites. As stated earlier, both sites have shown increased numbers of small *Quercus alba* trees. A similar trend was observed by Johnson and Law (1987) in a declining *Q. coccinea* stand on the Fristoe Unit of Mark Twain National Forest. This result suggests that *Q. alba* is going to have increased importance in the future canopy as the red oak group trees die.

In addition, both sites exhibited *Quercus* sapling densities which were lower than those of other species, while exhibiting seedling densities comparable to those of other species. Cho and Boerner (1991) observed such a sparse representation of *Quercus* species in the sapling layer in an Ohio "old-growth" forest, although *Quercus* species seedling density was relatively high. More mesic, shade tolerant species such as *Acer saccharum* and *Fagus grandifolia* dominated the sapling layer, suggesting that there was insufficient light reaching the forest floor to facilitate the release of the seedlings present. Since *Quercus alba* is more shade tolerant then *Q. coccinea* and *Q. velutina*, the other dominant species found on the forest floor of the xeric Ozark Mountains, one can speculate that it is best able to survive under a canopy that is less dense than that of the Ohio "old growth" forest. Johnson (1992) also observed an occurrence of low red oak group and high white oak group sapling density in two xeric ecosystems in Michigan. These sites were not undergoing accelerated mortality, and therefore the light levels required to release red oak group species regeneration on the forest floor may not have been present. From these findings one can suggest that in the Missouri Ozarks red oak group mortality may be allowing a new cohort of red oak group species to ultimately reach the canopy.

Even without frequent disturbance, oak regeneration usually is not a problem on xeric sites (Loftis 1983). These sites tend to support relatively stable communities that show little evidence of succession to more shade-tolerant, mesic species (Pallardy et al. 1988, 1991, Johnson 1992). Stands of oak species growing on xeric sites tend to accumulate reproduction in their understory in the form of sprouts and acorns, often for 50 years or longer (Johnson 1992). These ecosystems, characterized by such "auto-accumulating" reproduction, are therefore often self-sustaining (Johnson 1979, 1992).

The release of this accumulated reproduction often is dependent upon some source of reduction in canopy shading (Walters 1990). The mortality of *Quercus velutina* and *Q. coccinea* trees in the canopy could provide the increase in light needed by the shade intolerant oak seedlings. Under such conditions, sapling-sized individuals would likely be sparse relative to those in the seedling and canopy layers because of the lack of light reaching the forest floor prior to red oak group mortality (P.S. Johnson, personal communication).

In addition, red oak group mortality may also result in the release of advanced regeneration of *Q. alba* now present in the seedling layer. Therefore, it appears that both red oak group species and *Q. alba* will continue to dominate forest composition.

LITERATURE CITED

Beilmann, A.P., and L.G. Brenner. 1951. The recent intrusion of forests in the Ozarks. Ann. Missouri Bot. Gard. 38: 261-281.

Buckner, E. 1989. Evolution of forest types in the Southeast. pp. 27-33. In: Proceedings of Pine-Hardwood Mixtures: A Symposium on Management and Ecology of the Type. T.A. Waldrop, ed. Atlanta, GA.

Carvell, K.L. 1979. Factors affecting the abundance, vigor, and growth response of understory oak seedlings. pp. 23-29. In: Proceedings Regenerating Oaks in Upland Hardwood Forests, The 1979 John S. Wright Forestry Conference, H.A. Holt and B.C. Fischer, eds. Purdue University, West Lafayette, IN.

Cho, D.S., and R.E.J. Boerner. 1991. Canopy disturbance patterns and regeneration of Quercus species in two Ohio old-growth forests. Vegetatio 93: 9-18.

Cunningham, R.J., and C. Hauser. 1989. The decline of the Ozark Forest between 1880 and 1920. pp. 34-37. In: Proceedings of Pine-Hardwood Mixtures: a Symposium on the Management and Ecology of the Type. T.A. Waldrop, ed. Atlanta, GA.

Guyette, R.P., and B.E. Cutter. 1991. Tree-Ring analysis of fire history of a post oak savanna in the Missouri Ozarks. Nat. Areas J. 11: 93-99.

Hill, L.G. 1949. History of the Missouri Lumber and Mining Company, 1880-1909. Ph. D. dissertation. University of Missouri-Columbia, Columbia, MO. 289 pp.

Hinckley, T.M, Dougherty, P.M., Lassoie, J.P., Roberts, J.E., and R.O. Teskey. 1979. A severe drought: Impacts on tree growth, phenology, net photosynthesis, and water relations. Amer. Mid. Nat. 102: 307-316.

Jenkins, M.A. 1992. A study of oak decline and vegetation dynamics in the forests of the southeastern Missouri Ozark Mountains. M.S. thesis. University of Missouri-Columbia, Columbia, MO. 244 pp.

Johnson, L.J., and J.R. Law. 1989. A five year record of change for a declining scarlet oak stand in the Missouri Ozarks. In: Proceedings of the Seventh Central Hardwood Forest Conference, G. Rink and C.A. Budelsky, eds. Carbondale, IL, March 5-8., p. 103-107.

Johnson, P.S. 1982. Natural regeneration of upland hardwoods in the Upper Mississippi Valley. In: Proceedings of Hardwood Regeneration Conference, Winona, MN p. 22-37.

Johnson, P.S. 1992. New Perspectives and the silviculture of oak dominated forests in the central and eastern states. Unpublished paper, presented to the 1991 Society of American Foresters National Convention, San Francisco. 39 p.

Law, J.R., and J.D. Gott. 1987. Oak mortality in the Missouri Ozarks. In: Proceedings Sixth Central Hardwood Forest Conference, Knoxville, TN.

Loftis, D.L. 1983. Regeneration of oak in the Appalachians. pp. 32-38. In: Proceedings of Eleventh Annual Symposium of the Hardwood Research Council. Cashiers, NC.

Mueller-Dombois, D.J. 1987. Natural diebacks in forests. BioScience 37: 575-583.

Mueller-Dombois, D.J. 1988. Towards a unifying theory for stand-level dieback. GeoJournal 17: 249-251.

Pallardy, S.G., Nigh, T.A., and H.E. Garrett. 1988. Changes in forest composition in Central Missouri: 1968-1982. American Midland Naturalist 120:380-389.

Pallardy, S.G., Nigh, T.A., and H.E. Garrett. 1991. Sugar Maple invasion of oak forests of Missouri. Proceedings Oak Woods Management Workshop. J.E. Ebinger, ed. Charleston, IL.

Sander, I.L. 1983. Oak regeneration in the central states. pp. 18-30. In: Proceedings Eleventh Annual Hardwood Symposium of the Hardwood Research Council. Cashier, NC.

Sander, I.L., and F.B. Clark. 1971. Reproduction of upland hardwood forests in the central states. USDA Agriculture Handbook 405. 25 p.

Schuchard, O., and S. Kohler. 1984. Two Ozark rivers, the Current and Jacks Fork. University of Missouri Press, Columbia, Missouri. 130 p.

Walters, R.S. 1990. Influence of site on regeneration development after partial cutting of upland oak forests. p. 28. In: Forth Workshop on Seedling Physiology and Growth Problems in Oak Plantings. J.W. Van Sambeek, M.M. Larson eds. Gen. Tech. Rep. NC-139. USDA, Forest Service, North Central Experiment Station, St. Paul, MN. (Abstract).

Influence of Crown Class, Diameter, and Sprout Rank on Red Maple (*Acer rubrum* L.) Development During Forest Succession in Connecticut

Jeffrey S. Ward and George R. Stephens

Abstract: Crown class, stem diameter, and sprout rank of 2067 red maples on medium quality sites were measured at 10-yr intervals between 1927-1987. Nominal stand age was 25 yrs in 1927. There was a progressive increase in the probability of an individual red maple ascending into the upper canopy and persisting in the upper canopy from suppressed through dominant crown classes between ages 25-85. While 41% of dominant red maples remained in the upper canopy for any 30-yr period, less than 10% of intermediate red maples ascended into dominant or codominant crown classes. Mortality rates were highest for the lower crown classes between ages 25-85. Mortality rates between ages 25-55 ranged from 18% for dominant trees to 75% for suppressed trees. Within several diameter classes at age 25, survival through age 55, and the proportion found in upper canopy at age 55 was greater for the higher crown classes. Mortality increased by approximately 10% with each decrease in crown class for similarly-sized red maples. Mortality rates between ages 25- 55 were lower for the largest red maple in a sprout clump than for lesser sprouts and single stem red maples. Ingrowth was an important component of the lower crown classes, accounting for two-thirds of suppressed red maple at stand age 85. Red maple mortality rates decreased, and the rate of ascension into superior crown classes increased, following gypsy moth defoliations between 1961-64 and subsequent upper canopy oak mortality.

INTRODUCTION

Red Maple (*Acer rubrum* L.) accounts for over 8% of net hardwood growing stock volume in the United States and nearly 21% of the pole size class in the northeastern states (Waddell et. al 1989). Red maple is becoming an increasingly important component of the Connecticut forest. In 1985, red maple was the predominant species on 221,000 acres of sawtimber and 95,000 acres of poles and saplings, a 10% increase since 1972 (Dickson and McAfee 1988).

Red maple is a common understory species in many eastern oak forests (Walters and Yawney 1990), and is often a major component of young stands following final harvest of mature trees (Parker and Swank 1982, Beck and Hooper 1986, Ward and Heiligmann 1990). Red maple has the potential to eventually replace upper canopy oaks in unmanaged stands (Christensen 1977, Oliver and Stephens 1977, Abrams and Downs 1990, Nowacki et al. 1990, Stephens and Ward 1992). Some management practices have increased the proportion of red maple (Rudolph and Lemmien 1976, Heiligmann et al. 1985, Hill and Dickmann 1988, Kittredge and Ashton 1990, Abrams and Nowacki 1992). Gypsy moth outbreaks have accelerated red maple population increases in some locations by increasing overstory oak mortality (Collins 1961, Stephens 1981, Hix et. al 1991, Stephens and Ward 1992).

---

[1] Department of Forestry and Horticulture, Connecticut Agricultural Experiment Station, New Haven, Connecticut 06504.

Managing red maple has long been an anathema for foresters because of the high proportion of low quality trees (Walters and Yawney 1990). Consequently, research focusing on red maple has been minimal (Collins 1961, Wilson 1968, Lorimer 1984). Because red maple is a major competitor of more valuable hardwoods, e.g. northern red oak, it is imperative that we fully understand those factors which strongly influence red maple during stand development.

The objective of this research was to examine the influence of initial crown class, diameter, and sprout rank on 30-yr crown class transition rates for red maple in 25 and 55-yr-old stands; i.e. the probability of surviving and moving among crown classes, or dying between stand ages 25-55 and 55-85. Specifically, we proposed these hypotheses: (1) red maple crown class transition rates are independent of crown class, (2) red maple crown class transition rates are independent of diameter class, and (3) red maple crown class transition rates are independent of sprout rank.

STUDY AREA

The study areas are located in the Cabin (40 ac), Cox (50 ac), and Reeves Tracts (40 ac) of the Meshomasic State Forest, and in the Turkey Hill Tract (80 ac) of the Cockaponset State Forest. Elevations range from 300 to 550 ft m.s.l. Mean site index was 67 ft (reference age 50 yrs) on moderately well drained soils (Guinane 1985). We limited this study to the moderately well drained soils, excluding areas in excessively well drained or poorly drained soils. Soils are very stony to extremely stony fine sandy loams derived from gneiss and schist glacial tills and are acidic to strongly acidic (pH 4.5-6.0).

Plots are located in forests typical of many second-growth forests in southern New England. Most of the land was cleared for pasture or cultivation by the mid-1800's. The remaining woodlots were repeatedly cut for fuelwood and wood products, and burned by accident or to improve pasture for livestock grazing until the 1920's. The forests on these tracts originated around 1900 (Hicock et al. 1931). Upper canopy oaks were 80-yr-old in 1983 (Guinane 1985).

Upland oaks have dominated the upper canopy on medium quality sites throughout this study, accounting for over 50% of the upper canopy trees and 60% of upper canopy basal area since 1937 (Stephens and Ward 1992). Upper canopy density has steadily declined from 265 trees/ac in 1927 to 118 trees/ac in 1957 to 69 trees/ac in 1987 (Stephens and Ward 1992). Mean upper canopy dbh (diameter at 4.5 ft aboveground) increased from 5.1 inches in 1927 to 10.0 inches in 1957, and then increased to 13.6 inches in 1987. Red maple (*Acer rubrum*) and birch (*Betula lenta* and *B. alleghaniensis*) accounted for two-thirds of lower canopy trees in 1987 (Stephens and Ward 1992).

METHODS

The study was begun in 1926 in the Turkey Hill Tract. Cox, Reeves, and Cabin Tracts were added in 1927. Trees were mapped to the 0.66 ft (1 link) on transect segments 16.5 ft wide by 66 ft long (0.25 chain x 1 chain). Each transect had from 10 to 20 segments. Transects were spaced 264 ft (4 chains) apart on all tracts except Turkey Hill where transects were 330 ft (5 chains) apart. The centerline of each transect was permanently located by a stake and rock cairn at 132-ft (2 chain) intervals. This study used the 253 transect segments (6.3 ac) on medium quality sites which have not been disturbed since 1927. Segments which have been disturbed by partial cutting, road and trail construction, or fire were excluded.

The species, diameter, crown class, and sprout rank of each tree were recorded. Minimum dbh was 0.6 in prior to 1957; since 1957 the minimum dbh has been 0.5 in. Transect maps were used to relocate trees in the subsequent inventories of 1937 and 1957. Trees have been relocated since 1967 using the distance along the centerline together with the tree's position right or left of centerline. Sprout ranks within a clump were assigned by diameter, i.e. the tree with the largest diameter was assigned sprout rank 1, next largest was assigned sprout rank 2, etc. Sprout rank 0 was assigned to red maples which were not part of a sprout clump.

Crown class designations in 1927 and 1937 were likely based on Fernow (1917), which are nearly identical to those used in later surveys (Smith 1962). Crown class is a qualitative measure of relative canopy position (Smith 1962). Dominant trees have crowns extending above the general canopy level. Codominant trees form the larger part of the upper canopy and receive direct sunlight from above and on at least one side. Although intermediate trees extend into the upper canopy, they only receive direct sunlight from above. Suppressed trees do not reach into the upper canopy and receive no direct sunlight.

Crown class was not recorded for trees on the Turkey Hill Tract in 1926. Therefore, the crown class in 1926 was assumed to be the same as the crown class in 1937 for those trees on the Turkey Hill Tract which were first measured in 1926 and survived into 1937. Trees on the Turkey Hill Tract which died before 1937 were excluded from this study.

We define antecedent crown class as the crown class at the beginning of either 30-yr period. Resultant crown class is defined as the crown class at the end of either 30-yr period. Mortality during either 30-yr period was also considered a distinct resultant crown class. The distribution of stems (%) among resultant crown classes is synonymous with crown class transition rates and the two terms are used interchangeably throughout this paper.

Chi-square statistics (Neter et al. 1982) were used to determine whether the distribution of stems among crown classes in 1957 or 1987 (resultant crown classes) was independent of crown class in 1927 or 1957 (antecedent crown classes). Chi-square statistics were calculated using $CC_i \times CC_j$ contingency tables for the 30-yr periods between 1927-57 and 1957-87. CC_i were the antecedent crown classes in 1927 or 1957 with $i=1,2,3,4$ (dominant, codominant, intermediate, suppressed). CC_j were the resultant crown classes in 1957 or 1987 with $j=1,2,3,4,5$ (dominant, codominant, intermediate, suppressed, mortality). Contingency table cell values were the observed number of trees which had been in CC_i at the beginning of a 30-yr period and were in CC_j at the end of the 30-yr period. Differences in resultant crown class distributions in 1957 or 1987 were considered significant at $p \leq 0.01$.

The influence of sprout rank on red maple survival and development is not well understood. Sprout rank and antecedent crown class interactions were examined through 30-yr mortality rates. Because few sprout clumps had more than three sprouts, all sprout ranks ≥4 red maples were combined with sprout rank 3 trees for analysis. Differences in mortality rates for the 1927-57 and 1957-87 periods among crown classes and sprout ranks were tested using procedures in Neter et al. (1982, p325-329). Differences were considered significant at $p \leq 0.01$.

Diameter is correlated with crown class within a stand (Marquis 1991). To assess the influence of crown class independently of diameter, trees measured in 1927 were assigned to 5 diameter classes: 0.6-1.5, 1.6-2.5, 2.6-3.5, 3.6-4.5, and 4.6-5.5 inches dbh. Most red maples > 5.5 in dbh, and all > 7.5 in dbh, were in the dominant crown class. Differences in mortality rates between 1927-57 among crown and diameter classes were tested using procedures in Neter et al. (1982). Differences were considered significant at $p \leq 0.01$. We were unable to perform a similar analysis for the period between 1957-87 because diameters in 1957 were highly segregated by crown class; i.e. most trees in any 2-in or 4-in dbh class were confined to a single crown class.

RESULTS

Red maple density in each crown class at 30-yr intervals is shown in Table 1. There was a sharp drop in the densities of all crown classes between 1927-57. However, the relative density of red maple increased in the intermediate and suppressed crown classes. Mean diameter of red maple in all crown classes increased between 1927-57 (Table 2).

Table 1.—Absolute and relative density of red maple on medium sites by crown class and year

	Stems/acre			Percent of all stems		
Crown class	**1927**	**1957**	**1987**	**1927**	**1957**	**1987**
Dominant	7.0	1.3	1.4	7.7	2.1	4.2
Codominant	17.9	7.4	5.7	15.1	13.1	16.1
Intermediate	50.9	16.1	27.7	23.2	24.4	35.4
Suppressed	182.9	114.8	139.8	29.1	35.1	31.1

Table 2.—Mean diameter (inches) of red maple on medium sites by crown class and year

	Diameter		
Crown class	**1927**	**1957**	**1987**
Dominant	5.3	10.5	11.5
Codominant	4.3	7.2	9.5
Intermediate	2.7	5.1	5.7
Suppressed	1.3	2.1	1.9

The increase in red maple density between 1957-87 (Table 1) has been attributed to an ingrowth pulse following the defoliations between 1961- 64 (Ward 1988). Red maple ingrowth between 1957-87 was twice the 1927- 57 level (Table 3). By 1987, ingrowth accounted for two-thirds of suppressed red maple, up from 40% in 1957. Relative density also increased between 1957-87, as did mean diameter of all crown classes (Table 2), except for the suppressed crown classes.

Table 3.—Ingrowth (stems/acre) of red maple on medium sites by crown class and period

	Period	
Crown class at end of 30-yr period	**1927-1957**	**1957-1987**
Dominant & codominant	0.3	0.3
Intermediate	1.7	4.0
Suppressed	44.4	93.7

Crown Class Transition Rates

Red maple crown class transition rates between 1927-57 (Table 4) were not independent of antecedent crown class in 1927 (Table 5). Further analysis indicated crown class transition rates between 1927-57 were significantly different among all antecedent crown classes in 1927 (Table 5). There was not a marked distinction in crown class transition rates between upper and lower canopy red maples. Rather, there was an intergradation of crown class transition rates among antecedent crown classes; i.e. the crown class transition rates for each antecedent crown class were intermediate between crown class transition rates of the proximate antecedent crown classes.

Table 4.—Thirty-year crown class transition rates (%) of red maple on medium quality sites by antecdent crown class

Period	**Antecendent crown class**	**Resultant crown class (row percents)**					**Sample size**
		DOM[a]	**COD**	**INT**	**SUP**	**MORT**	
1927-57	Dominant	11.4	29.6	25.0	15.9	18.2	44
	Codominant	2.7	15.0	28.3	33.6	20.4	113
	Intermediate	.0	2.8	10.6	40.7	46.0	322
	Suppressed	.0	.5	1.2	23.3	75.0	1157
1957-87	DOM & COD[b]	12.7	30.9	20.0	12.7	23.6	55
	Intermediate	2.0	8.8	39.2	16.7	33.3	102
	Suppressed	.0	1.1	13.6	7.2	48.1	726

[a] DOM-dominant crown class, COD-codominant, INT-intermediate, SUP-suppressed, MORT-mortality.

[b] Dominant and codominant crown classes were combined because of insufficient trees (< 25) in the dominant crown class.

Between 1927-57 there was a 25% difference in mortality rates between codominant and intermediate trees, and a 29% difference in mortality rates between intermediate and suppressed trees (Table 4). Although mortality rates of dominant and codominant trees between 1927-57 were similar, there was a distinct difference in the proportion of red maple remaining in the upper canopy between 1927-57. Over 40% of dominant red maples, compared with 18% of codominant red maples, remained in the upper canopy through 1957. Few red maple in the intermediate and suppressed crown classes in 1927 were able to ascend into upper canopy positions by 1957.

Red maple crown class transition rates between 1957-87 (Table 4) were not independent of antecedent crown class in 1957 (Table 5). Further analysis indicated crown class transition rates between 1957-87 were significantly different among all antecedent crown classes in 1957 (Table 5). As in the 1927-57 period, crown class transition rates between 1957-87 demonstrated a pattern of intergradation among antecedent crown classes.

Mortality rates between 1957-87 were lower than for the preceeding 30- yr period, differing by approximately 10 percentage points among antecedent crown classes (Table 4). Transition rates into the upper canopy through 1987 for intermediate and suppressed crown classes remained below those for upper canopy red maples, but were 4x higher than for the 1927-57 period.

Table 5.—Pearson chi-square statistics for a comparison of red maple antecedent crown classes with resultant crown class distributions[a] for the periods 1927-57 and 1957-87. See Table 4 for actual distributions.

Period	Antecedent crown classes	Chi-square	DF	Probability
1927-57	All	599.0	9	< 0.001
	Dominant vs. codominant	10.7	3	< 0.013
	Codominant vs. intermediate	60.3	3	< 0.001
	Intermediate vs. suppressed	139.5	3	< 0.001
1957-87	All[b]	262.0	6	< 0.001
	Upper canopy vs. intermediate	22.8	3	< 0.001
	Intermediate vs. suppressed	86.5	3	< 0.001

[a] Resultant dominant and codominant crown classes were combined because of insufficient trees (< 25) in the dominant crown class.

[b] Antecedent dominant and codominant crown classes were combined because of insufficient trees (< 25) in the dominant crown class.

Canopy Position - Sprout Rank Interactions

Mortality rates between 1927-57 were not independent of sprout rank and crown class in 1927 (Table 6). Mortality was higher for the lower crown classes within a given sprout rank. Mortality nearly doubled with each decrease in crown class for sprout rank 1 (largest sprout in each clump) and sprout rank 0 (single stem) red maples. Interestingly, mortality between 1927-57 was significantly lower for sprout rank 1 than for sprout rank 0 red maples, especially in the suppressed crown class. Mortality was highest for red maples with a sprout rank ≥2. There was an interesting contrast between sprout rank 0 and 1 for those red maples in the upper canopy in 1927. Although mortality was higher for sprout rank 0 than for sprout rank 1, persistance in the upper canopy through 1957 was higher for sprout rank 0 trees, 36%, than for sprout rank 1 trees, 20%.

Similar patterns were noted for the 1957-87 period (Table 6). Within a given sprout rank, mortality was highest in the inferior crown classes. Mortality of sprout rank 1 red maples was not significantly lower than for sprout rank 0 between 1957-87. Mortality was highest for the lesser sprouts within a clump.

Crown Class - Diameter Class Interactions

As might be expected, diameter was not independent of crown class in 1927 ($F=712$, $d.f.=3$, $p<0.001$, $r^2=0.57$). Mortality rates between 1927-57 were not independent of crown class in 1927 for the diameter classes examined (Table 7). Within each diameter class 30-yr mortality rates were highest for those trees in lower crown classes. For example, mortality of upper canopy red maples in the 2.6-3.5 in dbh class was half the mortality of similarly sized trees in intermediate and suppressed crown classes. Although mortality was generally lower for trees with larger diameters within a given crown class, only for the suppressed crown class were these differences significant. Mortality was significantly different among most diameter classes when crown classes were combined.

Table 6.—Mortality (%) between 1927-57 and 1957-87 by crown class and sprout rank of red maple on medium quality sites. Only categories with a minimum of 25 trees are shown.

Period	Antecedent crown class	Sprout rank 0	1	2	>=3
1927-57	Upper canopy	23.2 a	11.5 a	-	-
	Intermediate	41.9 b	28.2 ab	60.9 c	70.5 c
	Suppressed	74.9 c	41.1 b	87.1 d	92.3 d
	Combined	66.1 b	31.0 a	75.7 c	85.9 d
1957-87	Upper canopy	30.3 ab	-	-	-
	Intermediate	25.0 a	24.2 a	-	-
	Suppressed	44.7 bc	40.6 abc	54.0 c	73.0 d
	Combined	41.7 a	36.2 a	54.0 b	73.0 c

[a] Mortality rates (%) for a given period followed by the same letter are not significantly different at $p \leq 0.01$. Significance levels for combined crown classes determined separately.

Table 7.—Mortality (%) between 1927-57 by crown class and diameter class in 1927 of red maple on medium quality sites. Only categories with a minimum of 25 trees are shown.

Crown class in 1927	Diameter class (in) in 1927 0.6-1.5	1.6-2.5	2.6-3.5	3.6-4.5	4.6-5.5
Upper canopy	-	-	22.2 a	14.6 a	18.5 a
Intermediate	55.6 bc	53.7 b	44.4 b	28.1 ab	-
Suppressed	78.9 d	68.2 c	49.1 b	-	-
Combined	78.2 a	62.9 b	41.7 c	21.8 d	19.1 d

[a] Mortality rates followed by the same letter are not significantly different at $p \leq 0.01$. Significance levels for combined crown classes determined separately.

DISCUSSION

Survival and development of red maple in 25 to 85-yr-old stands on medium sites was not independent of antecedent crown class (Tables 4 and 5), sprout rank (Table 6), and diameter class (Table 7). The utility of crown class for predicting red maple development and survival has been demonstrated across a wide geographical range including New Hampshire (Marquis 1969), New York (Lorimer 1981), and Wisconsin (Hix and Lorimer 1990, Hix and Lorimer 1991).

The amount of red maple which can expected in future stands depends not only on the absolute number of red maple, but also on the distribution of red maple among the crown classes. For example, using the crown class transition rates in Table3, each red maple in the upper canopy in a 55-yr-old stand requires approximately 2.4 dominant, 6.4 codominant, or 35.7 intermediate red maples in a 25-yr-old stand.

A period of drought between 1961-66 and repeated episodes of defoliation during 1961-64, 1971-72, and 1981 confound analysis of changes in class crown transition rates, including mortality, after 1957 (stand age 55). The first defoliations coincided with the stage in stand development when upper canopy competition shifts from height growth towards lateral crown expansion. No known major defoliation occurred prior to 1961 (Stephens and Waggoner 1970). Basal area mortality between 1957-67 was over 25%, three-fourths was oak (Stephens and Ward 1992). The post-defoliation mortality of the 1960s was similar to a partial harvest.

The combination of defoliation and natural succession likely contributed to the dramatic decreases in red maple mortality in all crown classes for the 1957-87 period compared to the 1927-57 period (Tables 4 and 5). Concurrently, the proportion of red maple remaining in the same crown class for 30-yrs doubled or tripled, and the proportion ascending in crown class increased by at least 4-fold. The increase in red maple density and crown class ascension following the oak defoliation (Collins 1961, Stephens 1981, Hix et. al 1991), appears to be a natural analogue of red maple increasing following partial cuttings (Rudolph and Lemmien 1976, Hilt and Dale 1982, Hill and Dickmann 1988, Kittredge and Ashton 1990, Ward 1992, Heiligmann and Ward 1993).

Additional evidence that partial removal of the overstory benefits red maple can found by contrasting this study with stand development between ages 37-80 yrs on medium quality sites in Massachusetts (Lorimer 1984). The stands in Massachusetts had received cultural treatments ranging from light thinning and improvement cuts to several precommercial weedings and a series of hardwood thinnings. Mortality rates of upper canopy red maples in Massachusetts, approximately 21% per 30-yr period (Lorimer 1984), were similar to the 18-24% 30-yr mortality rates observed in this study (Tables 4 and 5). However, suppressed red maple mortality rates in the Massachusetts stands, 17-29% per 30-yr period, were much lower than the 48-75% mortality rates observed in our stands. The series of partial overstory removal appears to have decreased mortality of lower canopy red maple and increased persistence of red maple within the upper canopy.

This study concurs with earlier research that upper canopy dominance by red maple in sapling-pole stands should not be an automatic cause of concern (Oliver and Stephens 1977, Oliver 1978, Hibbs 1983). Only a small fraction of red maples in subdominant crown classes in 25-yr-old stands were found in the upper canopy 30 yrs later and less than half of dominant red maples in 1927 persisted in the upper canopy through 1957 (Table 4).

CONCLUSIONS

This research provides information on the proportion of red maples in unmanaged stands 25 and 55-yrs-old which can be anticipated to maintain or change crown class, or die in the subsequent 30-yr period. Crown class designation provides a practical field method of determining the future status (upper canopy, lower canopy, or mortality) of individual red maples. Should the anticipated amount of red maple in the upper canopy exceed management objectives, then removal should focus on red maples in the dominant crown class. Only a small proportion of other red maples will be found in future upper canopies. In stands where anticipated red maple densities are below management goals, high thinning of trees other than red maple will decrease red maple mortality. High thinning will also increase persistence of those red maples already in the upper canopy.

REFERENCES

Abrams, M.D., and J.A. Downs. 1990. Successional replacement of old- growth white oak by mixed mesophytic hardwoods in southwestern Pennsylvania. Canadian Journal of Forest Research 20: 1864-1870.

Abrams, M.D., and G.J. Nowacki. 1992. Historical variation in fire, oak recruitment, and post-logging accelerated succession in central Pennsylvania. Bulletin Torrey Botanical Club 119: 19-28.

Beck, D.E., and R.M. Hooper. 1986. Development of a southern Appalachian hardwood stand after clearcutting. Southern Journal of Applied Forestry 10: 168-172.

Christensen, N.L. 1977. Changes in structure, pattern and diversity associated with climax forest maturation in Piedmont, North Carolina. American Midland Naturalist. 97: 176-188.

Collins, S. 1961. Benefits to understory from canopy defoliation by gypsy moth larvae. Ecology. 42: 836-838.

Dickson, D.R., and C.L. McAfee. 1988. Forest statistics for Connecticut— 1972 and 1985. USDA Forest Service Resource Bulletin NE-105.

Fernow, B.E. 1917. Forest terminology - report of committee. Journal of Forestry 15:68-101.

Guinane, T.L. 1984. Unpublished data. Connecticut Agricultural Experiment Station. New Haven, CT.

Heiligmann, R.B., E.R. Norland, and D.E. Hilt. 1985. 28-year-old reproduction on five cutting practices in upland oak. Northern Journal of Applied Forestry 2: 17-22.

Heiligmann, R.B., and J.S. Ward. 1993. Impact of three distinct diameter limit cuts on hardwood regeneration in upland oak stands: 20-yr results. Proceedings of the Central Hardwood Forest Conference IX. (in press).

Hibbs, D.E. 1983. Forty years of forest succession in central New England. Ecology 64: 1394-1401.

Hicock, H.W., M.F. Morgan, H.J. Lutz, H. Bull, and H.A. Lunt. 1931. The relation of forest composition and rate of growth to certain soil characters. Connecticut Agricultural Experiment Station Bulletin330.

Hill, J.P., and D.I. Dickmann. 1988. A comparison of three methods for naturally reproducing oak in southern Michigan. Northern Journal of Applied Forestry 5: 113-117.

Hilt, D.E., and M.E. Dale. 1982. Effects of repeated precommercial thinnings in central hardwood sapling stands. Southern Journal of Applied Forestry 6: 53-58.

Hix, D.M., D.E. Fosbroke, R.R. Hicks, and K.W. Gottschalk. 1991. Development of regeneration following gypsy moth defoliation of Appalachian Plateau and Ridge & Valley hardwood stands. P.347-359 in Proceedings of the 8 th Central Hardwood Forest Conference (L.H. McCormick and K.W. Gottschalk, eds.). Pennsylvania State University, University Park, PA, USA.

Hix, D.M., and C.G. Lorimer. 1990. Growth-competition relationships in young hardwood stands on two contrasting sites in southwestern Wisconsin. Forest Science 36: 1032-1049.

Hix, D.M., and C.G. Lorimer. 1991. Early stand development on former oak sites in southwestern Wisconsin. Forest Ecology and Management 42: 169-193.

Kittredge, D.B., and P.M.S. Ashton. 1990. Natural Regeneration patterns in even-aged mixed stands in southern New England. Northern Journal of Applied Forestry 7:163-168.

Lorimer, C.G. 1981. Survival and growth of understory trees in oak forests of the Hudson Highlands, New York. Canadian Journal of Forest Research 11: 689-695.

Lorimer, C.G. 1984. Development of the red maple understory in Northeastern oak forests. Forest Science 30: 3-22.

Marquis, D.A. 1969. Thinning in young northern hardwoods: 5-year results. USDA Forest Service Research Paper NE-139.

Marquis, D.A. 1991. Independent effects and interactions of stand diameter, tree diameter, crown class, and age on tree growth in mixed- species, even-aged hardwood stands. P.442-458 in Proceedings of the 8 th Central Hardwood Forest Conference (L.H. McCormick and K.W. Gottschalk, eds.). Pennsylvania State University, University Park, PA, USA.

Neter, A., W. Wasserman, and G.A. Whitmore. 1982. Applied Statistics. 2nd ed. Allyn and Bacon, Inc. Boston, MA.

Nowacki, G.J., M.D. Abrams, and C.G. Lorimer. 1990. Composition, structure, and historical development of northern red oak stands along an edaphic gradient in north-central Wisconsin. Ecology 36:276-292.

Oliver, C.D. 1978. The development of northern red oak in mixed stands in central New England. Yale University School of Forestry and Environmental Studies Bulletin 91.

Oliver, C.D., and E.P. Stephens. 1977. Reconstruction of a mixed-species forest in central New England. Ecology 58: 562-572.

Parker, G.R., and W.T. Swank. 1982. Tree species response to clear- cutting a southern Appalachian watershed. American Midland Naturalist 108: 304-310.

Rudolph, V.J., and W.A. Lemmien. 1976. Silvicultural cuttings in an oak- hickory stand in Michigan: 21-year results. P.431-453 in Proceedings of the Central Hardwood Forest Conference (J.S. Fralish, G.T. Weaver, and R.C. Schlesinger, eds.). Southern Illinois University , Carbondale. IL.

Smith, D.M. 1962. The practice of silviculture. 7th ed. Wiley & Sons, New York, NY.

Stephens, G.R., and P.E. Waggoner. 1970. The forests anticipated from 40 years of natural transitions in mixed hardwoods. Connecticut Agricultural Experiment Station Bulletin 707. New Haven, CT.

Stephens, G.R., and J.S. Ward. 1992. Sixty years of natural change in an unmanaged mixed hardwood forest. Connecticut Agricultural Experiment Station Bulletin 902. New Haven, CT.

Stephens, G.R. 1981. Defoliation and mortality in Connecticut Forests. Connecticut Agricultural Experiment Station Bulletin 796.

Waddell, K.L., D.D. Oswald, and D.S. Powell. 1989. Forest statistics of the United States, 1987. USDA Forest Service Resource Bulletin PNW-RB-168.

Walters, R.S., and H.W. Yawney. 1990. *Acer rubrum* L. - Red maple. P.60- 69 in Silvics of North America. Volume 2, Hardwoods. (R.M. Burns and B.H. Honkala, eds.). USDA Agriculture Handbook 654.

Ward, J.S., and R.B. Heiligmann. 1990. Effects of site quality and season of clearcutting on hardwood regeneration in Ohio. Northern Journal of Applied Forestry 7: 69-72.

Ward, J.S. 1988. Inventories at 10-year intervals reveal changes in Connecticut's forests. Frontiers of Plant Science 41: 7-8.

Ward, J.S. 1992. Response of woody regeneration to thinning mature upland oak stands in Connecticut, USA. Forest Ecology and Management 49: 219-231.

Wilson, B.F. 1968. Red maple stump sprouts: development the first year. Harvard Forest Paper 14. Harvard University Forest, Petersham, MA.

Formulating a Stand-growth Model for Mathematical Programming Problems in Appalachian Forests

Gary W. Miller and Jay Sullivan[1]

Abstract: Some growth and yield simulators applicable to central hardwood forests can be formulated for use in mathematical programming models that are designed to optimize multi-stand, multi-resource management problems. Once in the required format, growth equations serve as model constraints, defining the dynamics of stand development brought about by harvesting decisions. In large models representing forests with varying cover types equations from several unique simulators can be combined to account for individual stand growth. The inclusion of appropriate growth functions greatly enhances the validity and scope of management guidelines generated by optimization routines. Although several growth models are available for Appalachian hardwoods, few have been formulated to serve as inputs to such analytical models. Methods for formulating nonlinear growth constraints for a two-stage matrix simulator used in certain Appalachian hardwood stands are demonstrated. A generalized growth constraint is presented that may be indexed by size class, species group, and stand for sizable management problems.

INTRODUCTION

Forest growth and yield simulators play an important role in mathematical programming models designed to optimize forest management. In general, optimization models numerically search for a best management strategy from among all feasible alternatives. In forest management models, feasibility is defined by two types of mathematical constraints: landowner management objectives and stand growth capabilities. Equations that represent management objectives simply place limits on harvest decisions so that the optimization procedure considers only the cutting strategies that achieve desired esthetics, wildlife habitat, and so on. Conversely, equations derived from an appropriate stand growth model represent basic biological limits associated with the stand. This type of constraint places upper and lower bounds on residual tree growth resulting from harvest decisions.

Adams and Ek (1974) constructed a nonlinear programming (NLP) problem to solve for optimal structure, stocking, and transition harvesting for uneven-aged northern hardwoods. Within their model, tree growth and mortality over time were expressed as nonlinear functions of initial tree size and total stand basal area at the beginning of each growth period. The model searched for the optimal number of trees in each d.b.h. class at the beginning of a growth period such that the value of periodic growth was maximized. Martin (1982) developed investment-efficient stocking guides for uneven-aged northern hardwood stands using the same growth model and a Weibull distribution function to reduce the number of decision variables.

---

[1] U.S. Forest Service, Northeastern Forest Experiment Station, Timber and Watershed Laboratory, P.O. Box 404, Parsons, WV 26287; and Virginia Polytechnic Institute, and State University, Department of Forestry, Blacksburg, VA 24061.

Buongiorno and Michie (1980) later used the same plot data (Adams and Ek 1974) to estimate survival and growth probabilities for each diameter class, and to express growth capabilities in a fixed coefficient matrix. The matrix simply transformed an initial tree list to a new list 5 years later, thereby accounting for tree growth and mortality. By employing a matrix of transition probabilities, instead of nonlinear functions, the management model could be constructed as a linear programming (LP) problem. Although LP formulations are usually easier to solve, the fixed matrix does not change in response to cutting decisions, thus limiting its usefulness to problems involving narrow fluctuations in residual stocking.

To date, several simulators are available for eastern hardwood timber types: SILVAH for Allegheny hardwoods (Marquis and Ernst 1992), OAKSIM for even-aged upland oaks (Hilt 1985), NE-TWIGS for mixed eastern hardwoods (Teck 1990), and FIBER for spruce-fir and northern hardwoods (Solomon, Hosmer, and Hayslett 1987). Most available growth models were not designed to function as components of optimization models. Instead, they were developed to allow a user to input stand data, simulate stand development, and project volume and value growth in response to a specific cutting strategy. As a result, the structure of equations within the growth model that represent ingrowth, survival, diameter growth, and mortality often do not conform to requirements of algorithms used to solve mathematical programming problems.

This report demonstrates how equations from FIBER (Solomon, Hosmer, and Hayslett 1987) were used to construct growth constraints within a nonlinear programming problem to optimize individual stand management. FIBER was chosen because its relatively simple structure is amenable for use in nonlinear programming problems. Methods discussed are intended to help users construct similar models for forest management problems where FIBER is an accurate growth projection system.

GENERAL MANAGEMENT MODEL

A general model is described that can be used to optimize harvest schedules for a range of resource objectives. Forest managers need detailed cutting prescriptions that account for the interaction of size, species, and other product-value factors when planning harvests in individual stands. Cutting guides broadly defined by target residual basal area or volume per acre do not adequately describe how key economic factors such as size and species should be controlled to optimize management. Therefore, a basic requirement for this type of timber-oriented optimization model is that resulting prescriptions must define the number of trees to remove in each size class and species group over time.

Haight (1987) presented a model for uneven-aged management that solved for optimal cut and residual diameter distributions over a sequence of periodic harvests in a single stand. A more general version of the model, presented later by Getz and Haight (1989), is a discrete-time optimal control formulation that defines harvest sequences in terms of the number of trees to cut and leave in each size class. The state variable $x_{i,j,k}(t)$ defines the number of trees per acre at the beginning of time t, in size class i, in species group j, in stand k. The control variable $h_{i,j,k}(t)$ represents the number of trees per acre to harvest at time t, in size class i, in species group j, in stand k. The control vector $\mathbf{h}(t)$ could be broken down into roundwood products such as pulpwood, sawtimber, or veneer. For this discussion, however, $\mathbf{h}(t)$ represents only the harvest of merchantable sawtimber, commercial species 11.0 inches d.b.h. and larger.

The Objective Function

Optimization models include an objective function that simply measures the desirability of a particular solution. The solution algorithm systematically adjusts the level of the decision variables until no other solution has a higher objective function value. In this case, the objective function maximizes the present value of all harvests starting with an initial forest $\mathbf{x}(0)=\mathbf{x}_0$ as defined in equation 1.

$$Max \;\; NPV = \sum_{i=1}^{MD}\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{t=1}^{T} \delta^t \, p_{i,j,k}(t)\, h_{i,j,k}(t) - \sum_{t=1}^{T}\sum_{k=1}^{K} \delta^t \, fc_k(t) \tag{1}$$

The first term sums the product of price $p_{i,j,k}$ times number of trees harvested $h_{i,j,k}$, and discounts each harvest revenue to time $t=0$, where δ is equal to the discount factor $1/(1+r)$ and r is a positive annual discount rate. MD, J, K, and T represent the maximum diameter class, number of species groups, number of stands, and number of time periods, respectively. The second term is a fixed cost $fc_k(t)$ associated with each harvest discounted to $t=0$. This general formulation can be expanded to include variable harvest cost, value of ending inventory, planting costs, and so on.

Stand Growth Constraints

Stand growth constraints take the general form of equations 2 and 3. The number of trees at the beginning of the planning period $\mathbf{x}(0)$ is given as $\mathbf{x}_0$ in equation 2. In subsequent time periods, the initial number of trees $\mathbf{x}(t+1)$ is defined by two components given in equation 3. The first term $G(\mathbf{x}(t), \mathbf{h}(t))$ is a function that estimates growth of the residual stand from the previous period. The second term $F(\mathbf{x}(t), \mathbf{h}(t))$ is a function that estimates ingrowth into the smallest d.b.h. class from the previous period.

$$\mathrm{x}(0) = \mathrm{x}_0 \tag{2}$$

$$\mathrm{x}(t+1) = G(\mathrm{x}(t),\mathrm{h}(t)) + F(\mathrm{x}(t),\mathrm{h}(t)) \qquad t = 0,1,2,\ldots,T \tag{3}$$

Growth and yield simulators applicable to central hardwood forests can be formulated for use in a model of this type designed to optimize stand management. Transformed equations from the simulator take the form of equations 2 and 3 and serve as model constraints which define the dynamics of stand development brought about by harvesting decisions. In large models representing forests with varying cover types equations from several distinct simulators can be combined to account for individual stand growth.

Feasibility and Nonnegativity Constraints

Nonnegativity and feasibility constraints are defined by equations 4, 5, and 6.

$$\begin{aligned} h(t) &\geq 0 \\ x(t) &\geq 0 \end{aligned} \qquad t=0,1,2,\ldots,T \tag{4}$$

$$x_0 - h(0) \geq 0 \qquad t=0 \tag{5}$$

$$x(t) - h(t) \geq 0 \qquad t=1,2,\ldots,T \tag{6}$$

Equation 4 assures that all initial stands and harvests are nonnegative, and equation 5 assures that the initial harvest does not exceed stand stocking at time $t=0$, the initial stand state. Equation 6 assures that harvests do not exceed the initial stand in any time period t. Management constraints to achieve specific objectives can be added to this group of equations to further define feasibility.

FORMULATING GROWTH CONSTRAINTS

In this study, stand growth constraints corresponding to equation 3 were derived from FIBER, a two-stage matrix stand growth simulator originally developed for spruce-fir and northern hardwood types in the Northeast (Solomon, Hosmer, and Hayslett 1987). Growth functions in FIBER were developed from empirical studies to provide a mathematical framework for estimating growth dynamics that may result from management decisions. In general, stand growth is projected with a stage structured model that transforms the residual stand vector $\mathbf{x}(t)$-$\mathbf{h}(t)$ to a new initial stand vector $\mathbf{x}(t+1)$ in the future using a transition matrix whose elements are nonlinear functions of $\mathbf{x}(t)$ and $\mathbf{h}(t)$. These nonlinear growth functions estimate the probability that trees in the initial stand die, survive, and grow into a larger d.b.h. class, or survive without growing into a larger size class.

Basics of FIBER

Regression equations in FIBER employ initial basal area $IBA_k(t)$, residual basal area $RBA_k(t)$, diameter class midpoint D_i, proportion of total basal area comprising hardwood species in stand k, $PH_k(t)$, and proportion of total basal area comprising species j in stand k, $PS_{j,k}(t)$ at time t to predict transition and mortality probabilities over a 5-year period. For example, $u_{i,j,k}(t)$, the probability of a tree in d.b.h. class i, species j, stand k growing into d.b.h. class $i+1$ during a growth period beginning at time t is given by equation 7, where $\beta_{u,j}$ are estimated upgrowth coefficients for each species group j.

$$u_{i,j,k}(t) = \beta_{u,j}\ (IBA_k(t),\ RBA_k(t),\ PH_k(t),\ D_i) \tag{7}$$

Similarly, a transition probability is computed for $a_{i,j,k}(t)$, survival but no upgrowth in equation 8.

$$a_{i,j,k}(t) = \beta_{a,j}\ (IBA_k(t),\ RBA_k(t),\ PH_k(t),\ D_i) \tag{8}$$

$$f_{6,j,k}(t) = \beta_{f,j}\ (RBA_k(t),\ PH_k(t),\ PS_{j,k}(t)) \tag{9}$$

Mortality for the growth period is estimated implicitly as $1-a_{i,j,k}(t)-u_{i,j,k}(t)$. Ingrowth into the smallest size class, in this case 6 inches d.b.h., is given by equation 9. Transition probabilities are then placed into a matrix $\mathbf{G}_{j,k}(t)$ that is applied to a residual stand vector $\mathbf{x}_{j,k}(t)-\mathrm{h}_{j,k}(t)$ plus ingrowth defined by $f_{6,j,k}$ to generate a stand vector $\mathbf{x}_{j,k}(t+5)$ by equation 10. Note that stand growth is dependent on harvest decisions as they affect species composition and residual basal area in each time period.

$$\mathrm{x}_{j,k}(t+5) = \mathrm{G}_{j,k}\ (\mathrm{x}_{j,k}(t)\ -\ \mathrm{h}_{j,k}(t))\ +\ f_{6,j,k} \tag{10}$$

In summary, FIBER performs the growth simulation in two stages. In the first stage, elements of $\mathbf{G}(t)$ and $\mathbf{F}(t)$ are computed based on number of trees in each size class and species group before and after a harvest in each stand. In the second stage, a linear operation is performed according to equation 10 to estimate a new initial stand structure $\mathbf{x}(t+5)$ 5 years in the future. At each 5-year interval, the two-stage procedure is repeated so that growth is always a function of stand density and species composition at the beginning of each time period.

FIBER in Nonlinear Programming

For nonlinear programming problems, growth functions from FIBER are formulated as constraints that place upper and lower bounds on productivity of the stand, one growth constraint for each combination of diameter class i, species group j, and stand k. For example, the general constraint for $x_{18,j,k}(t+5)$, the number of trees in the 18-inch d.b.h. class in species j, stand k, at time $(t+5)$ is derived according to equation 11.

$$x_{18,j,k}(t+5) = a_{18,j,k}(t)\ (x_{18,j,k}(t)\ -\ h_{18,j,k}(t))\ +\ u_{16,j,k}(t)\ (x_{16,j,k}(t)\ -\ h_{16,j,k}(t)) \tag{11}$$

Coefficients $a_{18,j,k}$ and $u_{16,j,k}$ are probabilities for surviving residual trees at time period t remaining in the 18-inch d.b.h. class or growing up from the 16-inch class, respectively, during the growth period t to $t+5$. Equation 11 appears to be a linear operation, but transition probabilities are functions of $\mathbf{x}(t)$ and $\mathbf{h}(t)$ in terms of initial and residual basal area as shown in equations 12 and 13. Similar to the first stage of FIBER, transition probabilities for each diameter class i, each species group j, and each stand k are estimated by equations 12 and 13, plus ingrowth by equation 14, where β is a vector of regression coefficients estimated from growth data. There are 13 sets of regression coefficients in FIBER, one set for each species group.

$$\begin{aligned} a_{i,j,k}(t) = {} & \beta_{0,a,j} + \beta_{1,a,j} IBA_k(t) + \beta_{2,a,j} RBA_k(t) + \beta_{3,a,j} D_i + \beta_{4,a,j} PH_k(t) \\ & + \beta_{5,a,j} D_i^2 + \beta_{6,a,j} RBA_k^2(t) \end{aligned} \tag{12}$$

$$u_{i,j,k}(t) = \beta_{0,u,j} + \beta_{1,u,j} IBA_k(t) + \beta_{2,u,j} RBA_k(t) + \beta_{3,u,j} D_i + \beta_{4,u,j} PH_k(t) + \beta_{5,u,j} D_i^2 + \beta_{6,u,j} RBA_k^2(t) \qquad (13)$$

$$f_{1,j,k} = \beta_{0,f,j} + \beta_{1,f,j} RBA_k(t) + \beta_{2,f,j} PH_k(t) + \beta_{3,f,j} PS_{j,k}(t) \qquad (14)$$

Measures of stand stocking (RBA_k, IBA_k, PH_k, and PS_k) are functions of $\mathbf{x}(t)$ and $\mathbf{h}(t)$, computed as inner products of basal area at the midpoint of each d.b.h. class b_i and vectors $\mathbf{x}(t)$ and $\mathbf{h}(t)$ as shown in equations 15-18. Diameter classes range from 6 inches d.b.h. to *MD*, although 30 inches is the maximum recommended d.b.h. for the FIBER growth model. In equations 15 and 16, $IBA_k(t)$ and $RBA_k(t)$ include all species in a particular stand *k*, thus the subscript *j* was dropped for simplicity. In equation 17, *hd* represents hardwood species.

$$IBA_k(t) = 0.196\ x_{6,k}(t) + 0.349\ x_{8,k}(t) + \ldots + b_{MD}\ x_{MD,k}(t) \qquad (15)$$

$$RBA_k(t) = 0.196\ (x_{6,k}(t) - h_{6,k}(t)) + \ldots + b_{MD,k}\ (x_{MD,k}(t) - h_{MD,k}(t)) \qquad (16)$$

$$PH_k(t) = \frac{0.196\ x_{6,hd,k}(t) + 0.349\ x_{8,hd,k}(t) + \ldots + b_{MD}\ x_{MD,hd,k}(t)}{RBA_k(t)} \qquad (17)$$

$$PS_{j,k}(t) = \frac{0.196\ x_{6,j,k}(t) + 0.349\ x_{8,j,k}(t) + \ldots + b_{MD}\ x_{MD,j,k}(t)}{RBA_k(t)} \qquad (18)$$

In formulating explicit growth constraints, equations 15-18 are substituted into equations 12-14, and then for each diameter class, equations 12-14 are substituted into a general form of equation 11. A complete generalized growth constraint defined in equation 19 is constructed for each size class *i*, species group *j*, in each stand *k*. Basal area measured at the midpoint of each d.b.h. class is represented by b_i. Ingrowth defined in equation 14 is added to the smallest d.b.h. class in each time period *t*. Note that much of the nonlinearity associated with the model is attributed to squared terms involving decision variables in the growth constraints.

In practice, equation 19 must be expanded for each species group *j* and stand *k* included in the analyses. In the general form presented in equation 19, each initial stand variable $\mathbf{x}(t)$ and harvest control variable $\mathbf{h}(t)$ is indexed only by *i* for d.b.h. class, which is appropriate in the special case where there is only one stand containing a single species. In more practical applications, the NLP would contain growth constraints to represent all diameter classes, species groups, and stands included in the problem. FIBER can accommodate combinations of 13 species groups (Solomon, Hosmer, and Hayslett 1987).

$$\begin{aligned} x_i(t+1) = {} & (\beta_{0,a} + \beta_{1,a}\,[b_6 x_6(t) + \ldots + b_{MD}\, x_{MD}(t)] \\ & + \beta_{2,a}[b_6(x_6(t)-h_6(t)) + \ldots + b_{MD}(x_{MD}(t)-h_{MD}(t))] + \beta_{3,a} D_i \\ & + \beta_{4,a}[b_6 x_{6,hd}(t) + \ldots + b_{MD} x_{MD,hd}(t)] \,/\, [b_6(x_6(t)-h_6(t)) + \ldots + b_{md}(x_{MD}(t)-h_{MD}(t))] \\ & + \beta_{5,a} D_i^2 \\ & + \beta_{6,a}[b_6(x_6(t)-h_6(t)) + \ldots + b_{MD}(x_{MD}(t)-h_{MD}(t))]^2\ )\ (x_i(t)-h_i(t)) \\ & + (\ \beta_{0,u} + \beta_{1,u}\,[b_6 x_6(t) + \ldots + b_{MD} x_{MD}(t)] \\ & + \beta_{2,u}\,[b_6(x_6(t)-h_6(t)) + \ldots + b_{MD}(x_{MD}(t)-h_{MD}(t))] + \beta_{3,u} D_{i-1} \\ & + \beta_{4,u}[b_6 x_{6,hd}(t) + \ldots + b_{MD} x_{MD,hd}(t)] \,/\, [b_6(x_6(t)-h_6(t)) + \ldots + b_{MD}(x_{MD}(t)-h_{MD}(t))] \\ & + \beta_{5,u} D_{i-1}{}^2 \\ & + \beta_{6,u}\,[b_6(x_6(t)-h_6(t)) + \ldots + b_{MD}(x_{MD}(t)-h_{MD}(t))]^2\ )\ (x_{i-1}(t)-h_{i-1}(t)) \end{aligned} \tag{19}$$

EXAMPLE PROBLEM

The general management model was formulated as a sizable nonlinear programming problem and coded in the General Algebraic Modeling System (GAMS), a FORTRAN-based equation generator capable of representing complex models in compact form (Brooke, Kendrick, and Meeraus 1988). For problems with nonlinear constraints, the GAMS/MINOS optimizer employs a projected Lagrangian algorithm (Robinson 1972). An example problem is presented to demonstrate the performance of growth equations adapted from FIBER (Solomon, Hosmer, and Hayslett 1987).

The example problem simply required the NLP model to project individual stand growth to allow comparisons with actual stand growth and predicted stand growth using the FIBER simulator itself. Data were taken from a 55-year-old, second growth mixed hardwood stand on site index 64 (base age 50) for northern red oak. A 100 percent inventory from this 12.5-acre control stand was taken in 1964 and again in 1974 and 1984, allowing for comparison with 10- and 20-year growth projections from both FIBER and the NLP model.

The NLP model contained the objective function (equation 1), feasibility constraints (equations 4-6), growth constraints (equation 19), stand constraints to define the initial stand structure (equation 20), and management constraints to allow no periodic harvests (equation 21). Equation 20 simply requires that the initial stand structure $\mathbf{x}(0)$ must equal the 2-inch stand structure from the example stand $\mathbf{x}_0$ at time $t=0$.

$$x(0) = x_0 \tag{20}$$

In order to project stand growth in the absence of harvests, the harvest control variable $\mathbf{h}(t)$ was constrained to be equal to zero for all time periods in equation 21.

$$h(t) = 0 \tag{21}$$

With these constraints in place, the NLP problem simply determines the values for $\mathbf{x}(t)$, the initial number of trees in each species and size class, for each time period from $t=0$ to $t=20$ that satisfy the growth constraints derived from FIBER. Because no harvests are allowed in this example, the feasible region is reduced to a single point. The effect of the objective function has been nullified. Growth of the initial stand is deterministic, and should be approximately equal to projections from the FIBER software that utilizes the same regression coefficients.

A comparison of actual and projected stand structure and basal area stocking is shown in Table 1. Basal area projections from the nonlinear programming (NLP) formulation varied less than 2 percent from direct FIBER projections. Projected stand development varied from observed stand development less than 6 percent at 10 years and less than 8 percent at 20 years (Table 1). Direct FIBER projections were obtained from a modified algorithm that provided a 2-inch stand structure needed for this comparison (Marquis 1990). Discrepancies in stand structure projections are due to conversions from 1-inch stand structures generated by FIBER to 2-inch stand structures. Results indicated that modeling the growth simulator as a component of a nonlinear programming problem provided adequate stand table projections to allow numerical evaluations of management strategies.

Table 1.—Stand growth projections for a 55-year-old mixed hardwood stand on site index 64

			10-year			**20-year**	
Dbh	**Initial**	**Actual**	**NLP**	**FIBER**	**Actual**	**NLP**	**FIBER**
		number of stems/acre					
6	77.1	57.1	52.7	42.7	45.5	40.6	30.6
8	38.6	40.1	50.0	53.5	31.5	45.8	45.9
10	20.7	25.3	31.2	30.5	25.7	37.7	41.2
12	0.2	14.3	16.7	16.5	17.8	24.0	23.4
14	7.7	9.1	9.8	9.4	13.0	13.9	12.8
16	6.1	7.6	7.1	7.0	9.0	8.7	8.1
18	4.6	4.9	5.4	5.8	7.0	6.3	6.2
20	3.1	3.3	3.9	3.9	3.6	4.6	4.6
22	1.8	2.7	2.4	2.4	3.0	3.0	3.0
24	1.7	1.7	1.7	1.7	2.0	1.9	1.9
26	1.4	1.1	1.4	1.4	1.7	1.4	1.4
208	0	1.0	0.4	0.4	1.1	0.6	0.6
		ft ^{2}/acre					
Basal area	96.8	108.6	115.1	113.8	123.7	133.2	130.5

DISCUSSION

Formulating available stand-growth models for use in mathematical programming applications allows for relatively thorough analyses of management alternatives. Growth models typically are used to project the outcome of a specific cutting strategy. Users may compare projections for a range of strategies in an effort to find a "best" course of action. A major drawback of this approach is that superior strategies may be omitted from the analyses and thus overlooked. The mathematical programming approach allows all feasible alternatives to be considered, even those with very slight mathematical variation from others.

With nonlinear growth constraints from FIBER (Solomon, Hosmer, and Hayslett 1987), it is possible to construct multi-stand, multi-resource management formulations for forests where growth projections are valid. This type of model can optimize even-aged or uneven-aged silviculture for individual stands using the appropriate combination of management constraints. In addition, constraints such as minimum woodflow from an aggregate of stands may be imposed to assess the impact forest-level objectives on optimum harvest strategies for individual stands within the multi-stand problem.

Problem dimensions can increase rapidly when adding size classes, species groups, and time periods in a multi-stand problem. Relatively large problems may be solved using GAMS/386 for IBM-compatible personal computers equipped with appropriate memory. The model presented in this report was expanded to 12 size classes, 2 species groups, 3 stands, and 21 time periods covering a 100-year planning horizon. Optimal solutions were obtained in less than 3 hours cpu time on a 386-20 MHz processor.

LITERATURE CITED

Adams, D.M.; A.R. Ek. 1974. Optimizing the management of uneven-aged forest stands. Canadian Journal of Forest Research 4(3):274-287.

Brooke, A.; D. Kendrick; A. Meeraus. 1988. GAMS: A user's guide. San Francisco, CA: The Scientific Press. 289 p.

Buongiorno, J.; B.R. Michie. 1980. A matrix model of uneven-aged forest management. Forest Science 26(4):609-625.

Getz, W.M.; R.G. Haight. 1989. Population harvesting demographic models of fish, forest, and animal resources. Princeton, NJ: Princeton University Press. 359 p.

Haight, R.G. 1987. Evaluating the efficiency of even-aged and uneven-aged stand management. Forest Science 33(1):116-134.

Hilt, D.E. 1985. OAKSIM: An individual tree growth and yield simulator for managed, even-aged, upland oak stands. Res. Pap. NE-562. Radnor, PA: U.S. Department of Agriculture, Forest Service. Northeastern Forest Experiment Station. 21 p.

Marquis, D.A. 1990. A multi-resource silvicultural decision model for forests of the Northeastern United States. In: Proceedings, Division I, IUFRO Congress, Montreal, Canada. p. 419-431.

Marquis, D.A.; R.L. Ernst. 1992. User's guide to SILVAH: stand analysis, prescription, and management simulator program for hardwood stands of the Alleghenies. Gen. Tech. Rep. NE-162. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 124 p.

Martin, G.L. 1982. Investment-efficient stocking guides for all-aged northern hardwood forests. Res. Pap. R3129. Madison, WI: University of Wisconsin, College of Agriculture and Life Science. 12 p.

Robinson, R. A. 1972. A quadratically convergent algorithm for general nonlinear programming problems. Mathematical Programming 3. 145-156.

Solomon, D.S.; R.A. Hosmer; H.T. Hayslett, Jr. 1987. FIBER handbook: A growth model for spruce-fir and northern hardwood types. Res. Pap. NE-602. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 19 p.

Teck, R.M. 1990. NE-TWIGS 3.0: An individual tree growth and yield projection system for the Northeastern United States. The Compiler. 8(1):25-27.

Production Rates and Costs of Group-Selection Harvests with Ground-Based Logging System

Chris B. LeDoux[1], Michael D. Erickson[2], and Curt C. Hassler[2]

Abstract: As increased demands are placed on forest land for timber production, wildlife, esthetics, recreation, hunting, fishing, and other uses, owners of woodlots and forest land are looking for different ways to harvest or treat the stands to accomplish their objectives. The large clearcut harvest blocks that had been the standard for years with the forest industry are not always acceptable. The contemporary emphasis is on harvesting trees using partial and tree-selection cuts, thinnings, and group-selection methods. Group-selection involves taking small groups or clumps of trees in a somewhat random pattern to capture mortality, wood or weather damage, insect or disease infestations; to regenerate stands; and to harvest financially mature trees. As the size of group/clump (size of opening) decreases, so does the volume and value to be removed. How much the logging costs increase by decreasing the size of opening was the focus of this study. Cost and production information was developed to make decisions about harvesting units of different sizes with ground-based logging systems. The harvest units ranged from one-half to two acres in size.

INTRODUCTION

Changing times and attitudes toward forest land have changed the way timber is managed. As increased demands are placed on forest land for timber production, wildlife habitat, esthetics, recreation, hunting and fishing, as well as a multitude of other uses, owners of forest land are looking for different ways to manage timber stands to attain individual objectives. A growing number of small nonindustrial private landowners believe that clearcutting is an undesirable timber management method, especially when done on a large scale with cut blocks greater than 5 to 10 acres in size. These large clearcut harvests, which have been the standard for years in the forest industry, are not always acceptable, and are often viewed as degrading both visually and to the forest ecosystem. The contemporary emphasis is on harvesting timber using partial and tree-selection cuts, thinnings, and group-selection methods. These silvicultural harvesting methods recognize the long-term effects and benefits of good forest management above and beyond past methods that generally focused on only the short-term revenues realized from a timber harvest.

Group-selection involves harvesting small groups or clumps of trees in a somewhat random pattern across a stand to capture mortality, insect and disease infestations; to regenerate stands; and to harvest financially mature trees. The group-selection method has certain advantages over single-tree selection cuttings. Harvesting older mature trees can be carried out more economically and with less damage to the residual stand. There is greater latitude for creating the kind of environmental conditions necessary for reproduction. The reproduction develops in clearly defined even-aged aggregations, which is a substantial advantage in developing good tree form, especially in hardwoods (Smith 1986).

---

[1] Supervisory Industrial Engineer, USDA Forest Service, Northeastern Forest Experiment Station, 180 Canfield Street, Morgantown, WV 26505, telephone: 304-285-1572.

[2] Research Associate; Associate Professor and Leader, Appalachian Hardwood Center, Division of Forestry, West Virginia University, Morgantown, WV 26506-6125, telephone: 304-293-3826.

Group-selection cuttings also create gaps in the forest canopy that can increase the area of favorable habitat for wildlife. Many species of wildlife benefit from the combination of environmental conditions existing within and along the boundaries between the young reproduction and older trees. Several kinds of protective cover are available in close proximity to various food plants that may be fostered by the broad spectrum of microclimatic conditions existing between the edges and the centers of the young groups.

Group-selection harvest studies in eastern hardwoods have shown that economic success of such harvests rests heavily on product market values, tree quality, and logging costs (Boucher and Hall 1989, Bell 1989, LeDoux et. al. 1991, Brummel 1992, Erickson et. al. 1992). Other studies have attempted to define group-selection harvests and where they can be used (Roach 1974). Additional studies have documented the reproduction of hardwoods 10 years after cutting as affected by site and opening size (Minckler and Woerheide 1965). In this study, the group-selection units are defined as small groups, 2 acres or less in area, on which most of the trees will be harvested.

The studies reported above, although valuable, do not provide detailed time and motion data for ground-based systems operating in group-selection units. This report summarizes results of comprehensive, detailed time studies for ground-based systems operating in Appalachian upland hardwood stands.

LOGGING SITES AND STUDY METHODS

Data for the study were collected from a commercial logging operation on the West Virginia University Experimental Forest, Monongalia County, West Virginia. The study area was approximately 54 acres in size. Stand composition across the study site was composed of Appalachian hardwoods dominated by yellow-poplar (*Liriodendron tulipifera*), northern red oak (*Quercus rubra*), chestnut oak (*Quercus prinus*), black cherry (*Prunus serotina*), red maple (*Acer rubrum*), as well as several other species of lesser importance. Within the 54-acre study area, treatment plots representing group-selection harvest blocks of 0.5, 1.0, 1.5, and 2.0 acres were located and replicated 4 times for a total of 16 cutting plots totaling 20.0 acres (Figure 1). Plots were located so individual treatments were separated by a buffer zone of approximately 150 to 200 feet.

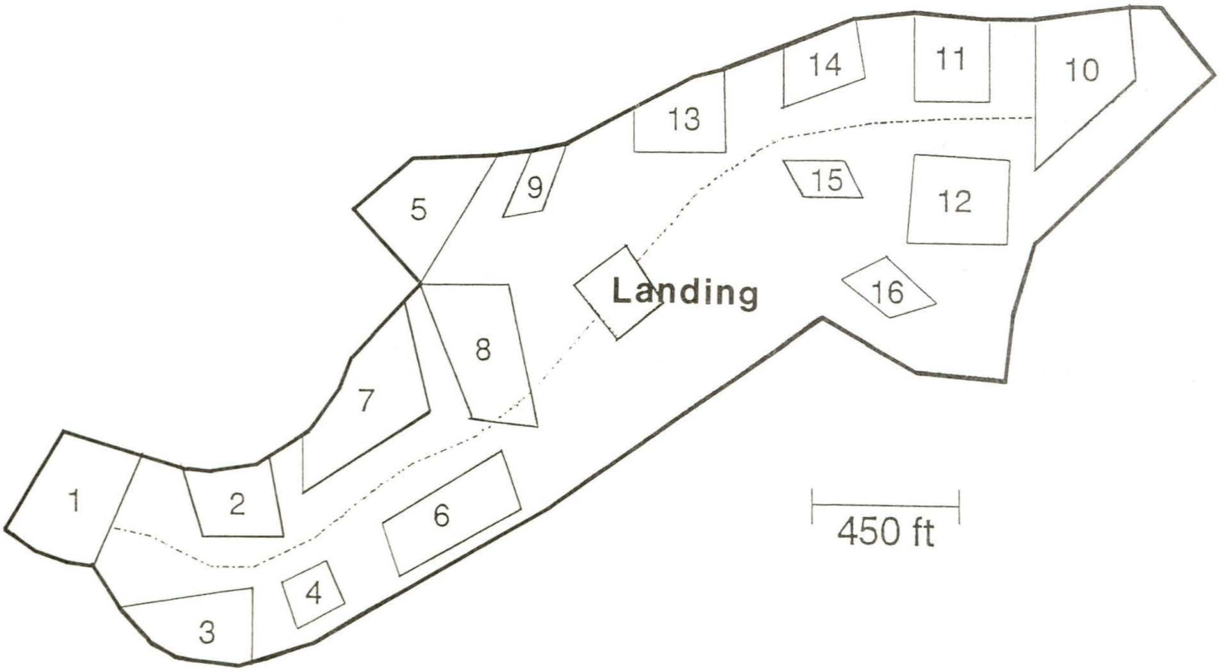


Figure 1.—Group-selection harvest units, plot boundaries, landing, and primary skid trail locations.

Before harvesting the group-selection units, a single centrally located landing and two primary designated skid trails from which the individual plots could be accessed were flagged in (Figure 1). The landing and skid trails, after being reviewed by the logging contractor and modified where deemed necessary, were developed before the cutting and skidding activities began. Within each of the harvest units, designated skid trails were not used and skidding was performed with a random approach, so long as the designated trails were used for entry and exit from the plots.

All trees within each group-selection unit, both sawtimber and pulpwood size, were chainsaw felled, limbed, and topped. All stems were processed into tree-length material with utilization levels in the form of minimum-top diameters left up to the cutters. Skidding of the processed tree-length materials on each of the study units was completed by one of three John Deere 640D cable skidders[3], each operated by one of four skidder operators. For the most part, skidding on an individual plot was performed by a single operator and sometimes two operators in an attempt to eliminate some of the system imbalances that may have occurred if all three machines were working in close proximity in the small cutting units. In addition to this, once an operator began skidding from a treatment block the operator was restricted to skidding the block to its completion so as not to complicate the collection of the time study data.

Continuous time and motion study data were collected for the skidding component for each of the treatment plots. All skidding element times, both productive and non-productive delay were recorded by data collectors stationed both at the study plot sites and at the landing. In addition to productive and delay element times, additional skidding parameters including skid distance, number of stems per turn, volume per turn, number of machine moves in a hooking cycle, as well as a number of other variables were recorded for each skidding cycle. Because of a shortage in available data collectors during two days of the harvest operation, detailed data were not collected for plots 4 and 5, so these plots were eliminated from the study. Continuous time data were collected on a total of 715 skid cycles involved in skidding the remaining 14 group-selection units in the study.

TIME STUDY RESULTS

Average total cycle time was greatest on groups of 0.5 and 1.0 acres and lowest on the groups of 1.5 and 2.0 acres, respectively (Table 1). The difference in total cycle time resulted primarily from the differences in mean one-way skid distance; about 1,100 feet for 0.5- and 1.0-acre groups and about 1,050 feet for groups of 1.5 and 2.0 acres. Average logs hooked per cycle were slightly larger on groups of 1.0 and 2.0 acres. The average number of winching cycles (pulls/cycle) to form a turn were relatively consistent for all groups. Average volume/cycle was about the same for all size groups with turn volumes of about 140 ft^3. For all groups combined, production averaged about 540.67 ft^3 per delay-free hour and 450 ft^3 per scheduled hour (Table 1).

Average cycle delay was about the same for all groups ranging from no delay to a maximum of 26 minutes for all groups (Table 1). Most delay time was attributed to nonproductive personal delays, feller/bucking, and system imbalance (Figure 2). For all groups, delay time averaged about 17 percent of total scheduled time.

---

[3] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endoresement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

Table 1.—Summary time study statistics for skidding cycles, averages and ranges

Variable	**Group size**				**All groups**
	0.5	**1.0**	**1.5**	**2.0**	
Number cycles	65	184	172	294	715
Total cycle Time (min)	17.41 (8.17-29.35)	17.29 (8.08-28.94)	15.68 (8.32-30.88)	14.96 (5.13-28.23)	15.95 (5.13-25.98)
Cycle delay (min)	2.75 (0-14.32)	3.27 (0-22.76)	3.51 (0-25.98)	3.10 (0-22.33)	3.21 (0-25.98)
Outdistance (ft)	1111 (572-2104)	1099 (500-1574)	1041 (422-1654)	1072 (200-2187)	1075 (200-2187)
Indistance (ft)	1106 (572-2104)	1098 (420-1574)	1034 (422-1654)	1068 (200-2187)	1071 (200-2187)
Number logs/ cycle	4 (1-8)	4.4 (1-9)	3.9 (1-7)	4.7 (1-9)	4.4 (1-9)
Moves/ cycle	.16 (0-1)	.23 (0-2)	.19 (0-2)	.28 (0-2)	.24 (0-2)
Pulls/ cycle	1.23 (1-2)	1.28 (1-3)	1.27 (1-3)	1.35 (1-3)	1.30 (1-3)
Volume/ cycle (ft^3)	153.86 (34-333)	128.61 (22-254)	149.66 (30-333)	147.57 (24-391)	143.76 (22-391)
Production Total (ft^3/hr)	457.78	375.42	468.04	490.22	450.08
Delay free (ft^3/hr)	530.37	446.35	572.86	591.87	540.67

[a]Mean value
[b]Range

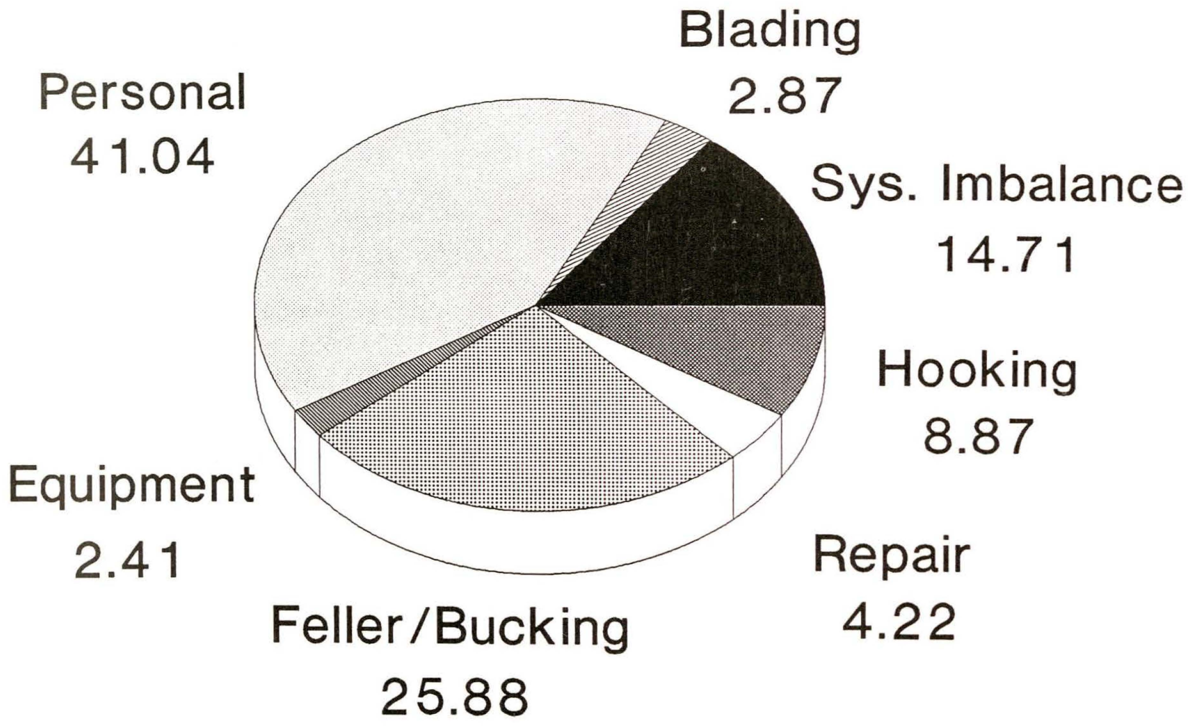


Figure 2.—Breakdown of delays as a percentage of total delay time.

Ordinary least-squares regression analysis was performed on the time-study data to develop a prediction equation for estimating delay-free cycle time. The data from all groups and operators were pooled for this analysis. A stepwise regression procedure examined the effect of several variables on skidding cycle time. Variables selected were roundtrip distance/2, number of logs/turn, number of winching cycles to form a turn (pulls/cycle), cubic foot volume/turn, and dummy variables for group size of 0.5, 1.0, and 1.5 acres. Cycle time can be estimated for 2.0-acre groups by substituting zeros for all group size coefficients. The regression equation was chosen by comparing R^2 values and levels of significance of variables.

For the following equation, regression statistics are: N=715, R^2=0.487, standard error of the estimate = 3.023. All partial regression coefficients are significant at the 0.05 level.

$$\begin{aligned} Y = 5.41 &+ 2.71X_1 \\ &+ 2.54X_2 \\ &+ 1.40X_3 \\ &+ 0.00485X_4 \\ &+ 0.319X_5 \\ &+ 1.63X_6 \\ &- 1.59X_7 \\ &+ 0.00437X_8 \end{aligned}$$

where:
Y = delay-free cycle time - min;
X_1 = group size dummy variable; with size of 0.5 acres, $X_1=1$, otherwise $X_1=0$;
X_2 = group size dummy variable; with size of 1.0 acres, $X_2=1$, otherwise $X_2=0$;

X_3 = group size dummy variable; with size of 1.5 acres, X_3=1, otherwise X_3=0;
X_4 = Roundtrip distance/2, feet;
X_5 = Number of logs/turn;
X_6 = Number of winching cycles to form a turn;
X_7 = Prebunched logs dummy variable, when logs are prebunched, X_7=1, otherwise X_7=0;
X_8 = turn volume, ft^3.

SKIDDING COST ANALYSIS

The production data from Table 1, the cycle-time equation, and an hourly machine rate cost of $36.94 for the skidder and operator were used to illustrate the incremental effect of each variable on skidding costs. The $36.94 hourly rate is based on all new equipment and does not allow for profit and risk. The output was used to develop Figures 3-6, which show the effect and sensitivity of each respective variable in the regression equation upon cost per unit of volume skidded. The variable of interest was allowed to change value while all other variables within the equation were held constant at their observed mean values.

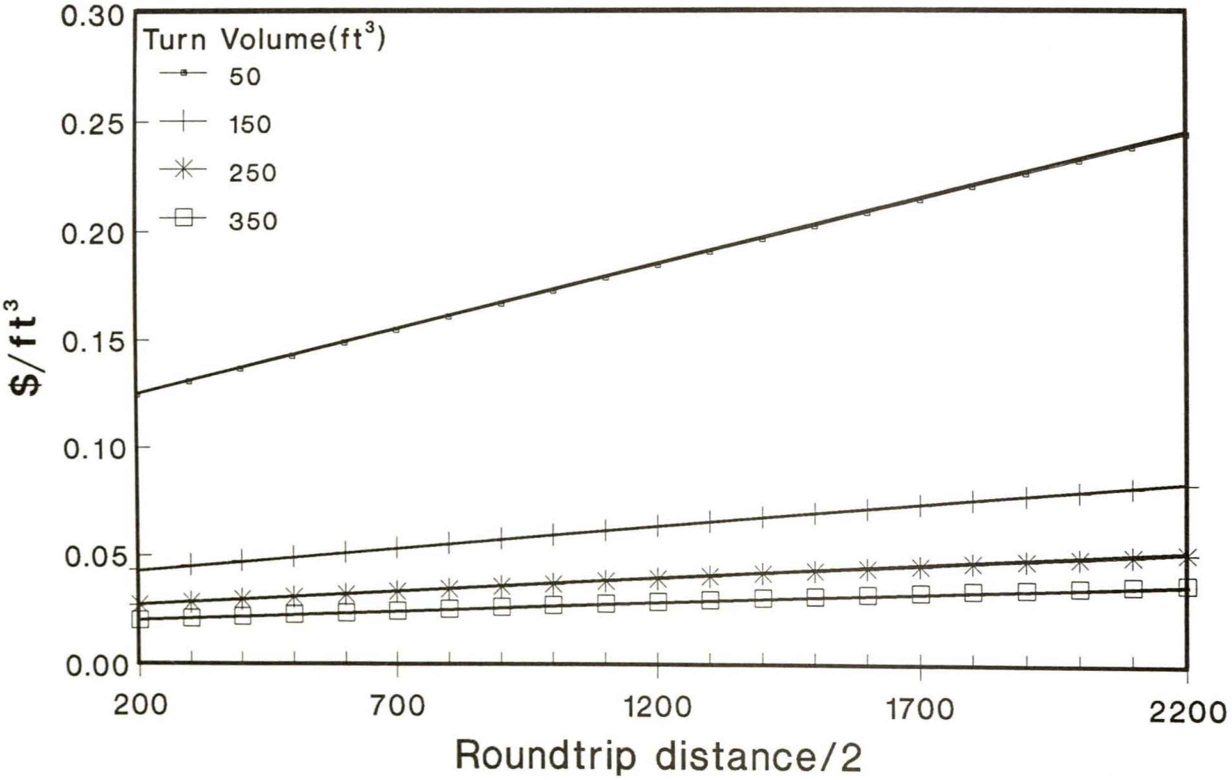


Figure 3.—Effects of slope distance and volume per turn on estimated skidding cost. Conditions: size of group = 2 acres, 4.4 logs/turn, 1.3 pulls/turn, and no prebunched logs.

Figure 3 demonstrates the effects of slope skid distance and volume/turn hooked on estimated skidding cost for average conditions. These results indicate that as slope skid distance increases, production decreases and unit cost increases. For example, a logger planning to log units where the average slope skid distances would be about 700 feet with 50 ft^3 turns could expect a cost of

$0.154/ft³ (Figure 3). However, extending slope distance to 2,000 feet would increase cost by about 50 percent to $0.232/ft³ for the same turn size. Similarly, going from hooking 50 ft³ turns to 350 ft³ turns at a distance of 700 feet would decrease cost by 84 percent from $0.154/ft³ to $0.024/ft³. Hooking 150 ft³/turn versus 50 ft³/turn at 700 foot distances would decrease costs by 65 percent, illustrating the importance of hooking larger turn volumes.

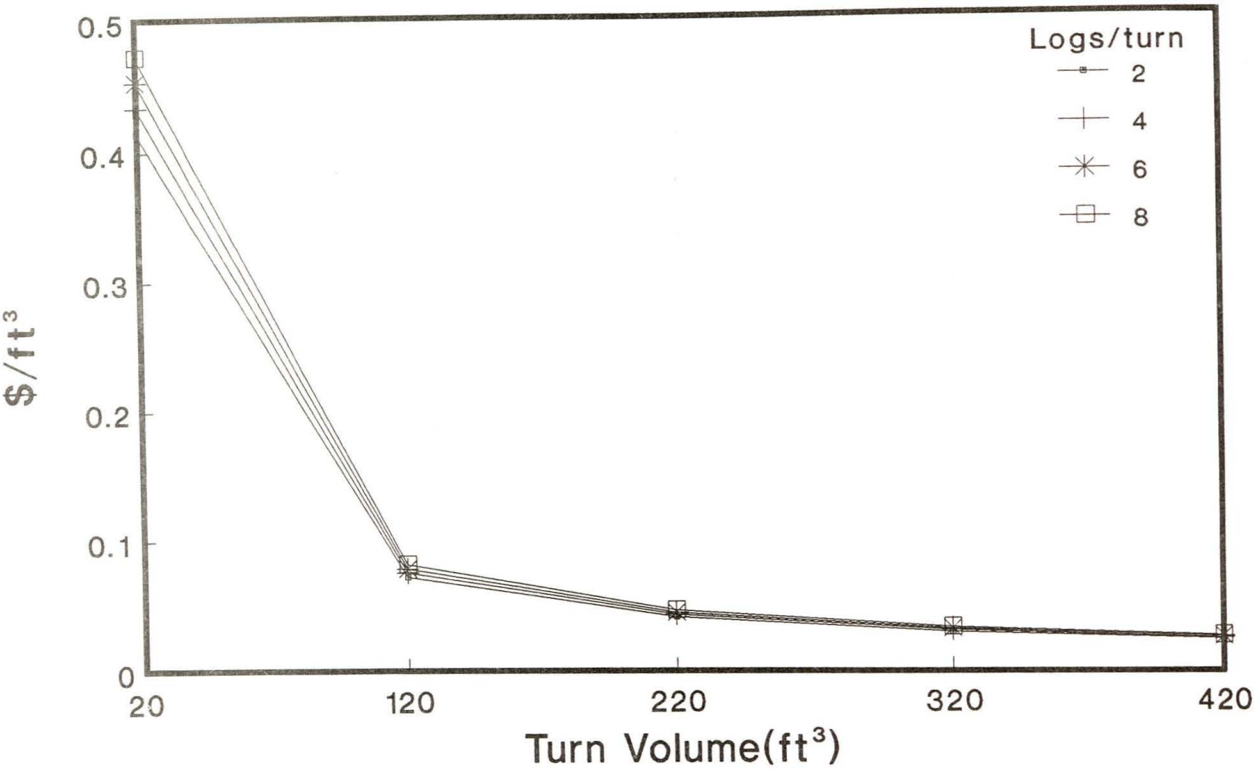


Figure 4.—Effects of volume per turn and logs/turn on estimated skidding costs. Conditions: slope distance is 1,073 feet, size of group = 2 acres, 1.3 pulls/turn, and no prebunched logs.

Figure 4 demonstrates the effects of turn volume and logs per turn on the estimated skidding cost for average conditions. For example, the cost to skid two logs that form a turn size of 20 ft³ is $0.414/ft³. Hooking eight logs to form the same turn size increases the cost by about 14 percent to $0.473/ft³. This increase is due to the time involved in hooking additional pieces to form a given turn size. However, hooking additional logs of a given size to form larger turns decreases cost. For example, hooking two logs to form a 20 ft³ turn costs $0.414/ft³, whereas hooking the same two logs to form a 320 ft³ turn decreases cost by about 93 percent to $0.028/ft³. These results illustrate the importance of skidding large logs and turns to keep cost down. These results indicate the importance of planned turn building, that is, hooking as much volume as allowed by log-size distributions and machine payload constraints. Skidding small roundwood will decrease the average log and turn size resulting in increased costs/unit volume.

Figure 5 demonstrates the effect of pulls/cycle and turn volume on cost/unit for average conditions. The number of pulls (winching cycles) needed to form a turn will affect production and costs. For example, hooking 50 ft³/turn requiring one pull costs about $0.170/ft³. For the same conditions, requiring two pulls increases cost by 12 percent to $0.190/ft³. When three pulls are

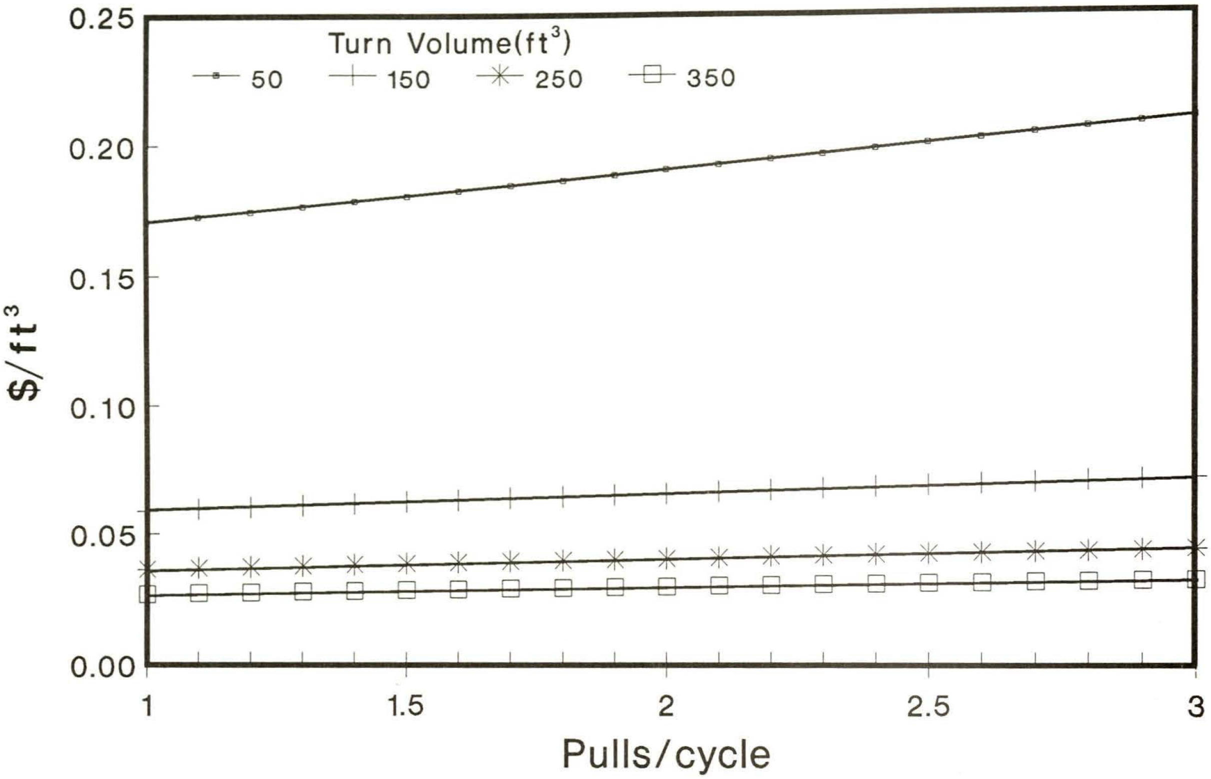


Figure 5.—Effects of pulls/cycle and turn volume on estimated skidding costs. Conditions: size of group = 2 acres, slope distance is 1,073 feet, 4.4 logs/turn, 1.3 pulls/turn, and no prebunched logs.

required to form the same turn, cost increases by 23 percent from \$0.170/ft^3 to about \$0.210/ft^3. However, one pull to hook a 50 ft^3 turn costs \$0.170/ft^3. For the same number of pulls but hooking a larger turn of 350 ft^3, cost decreases by about 85 percent to \$0.026/ft^3. This again illustrates the importance of turn size on production and cost.

Figure 6 shows the effect of logs/turn and log size on cost of skidding different log and turn sizes for average conditions. Hooking one 16 ft^3 log costs about \$0.504/ft^3. Hooking nine 16 ft^3 logs to form a 144 ft^3 turn reduces cost by about 86 percent from \$0.504/ft^3 to \$0.069/ft^3. By contrast, hooking one 64 ft^3 log versus a 16 ft^3 log decreases cost from \$0.504/ft^3 to \$0.128/ft^3 or about 75 percent.

To determine the cost of skidding different size units, move-in-and-out costs were calculated and added to skidding cost (Figure 7). When group-selection harvests result in very small and scattered harvest units that require frequent moves between units, then the cost to move in and out of each unit can become prohibitive. Move-in-and-out costs include wages and system-fixed costs incurred when moving equipment. The costs in Figure 7 were calculated by adding estimated skidding costs for each group size and the average conditions sampled to the move-in-and-out costs (move cost/(total area cut * volume/acre)). The assumed volume/acre equalled 3,000 ft^3 for all units skidded. These results indicate that costs decline rapidly with increasing harvest unit area, and that minimizing move costs and keeping the unit area 1. acres or larger can avoid excessive harvesting costs (Figure 7). Obviously, for very small scattered groups, the costs could be prohibitive. Most variables were held at their observed mean values so that results will change if other than mean values are used as constants. For example, increasing volume/acre would have an effect similar to that of increasing the harvesting unit area.

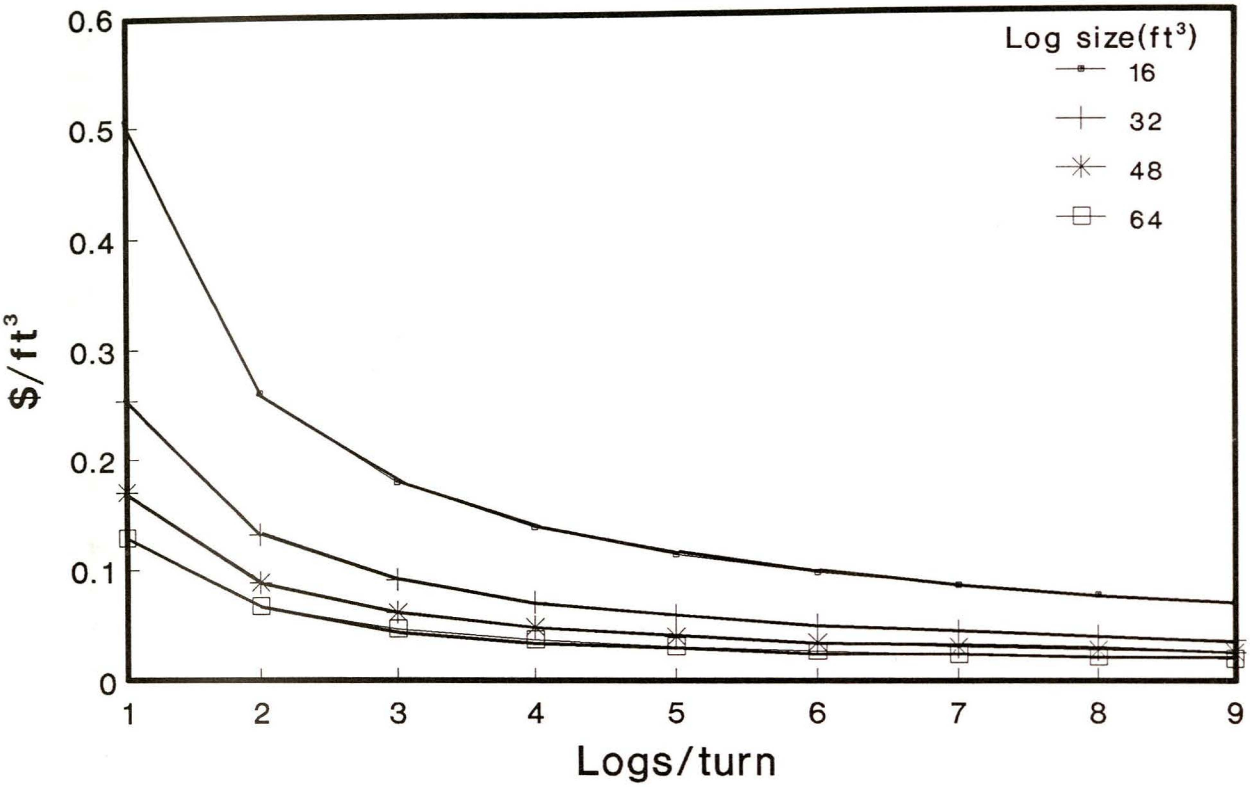


Figure 6.—Effects of logs/turn and log size on estimated skidding cost. Conditions: size of group = 2 acres, slope distances is 1,073 feet, 1.3 pulls/turn, and no prebunched logs.

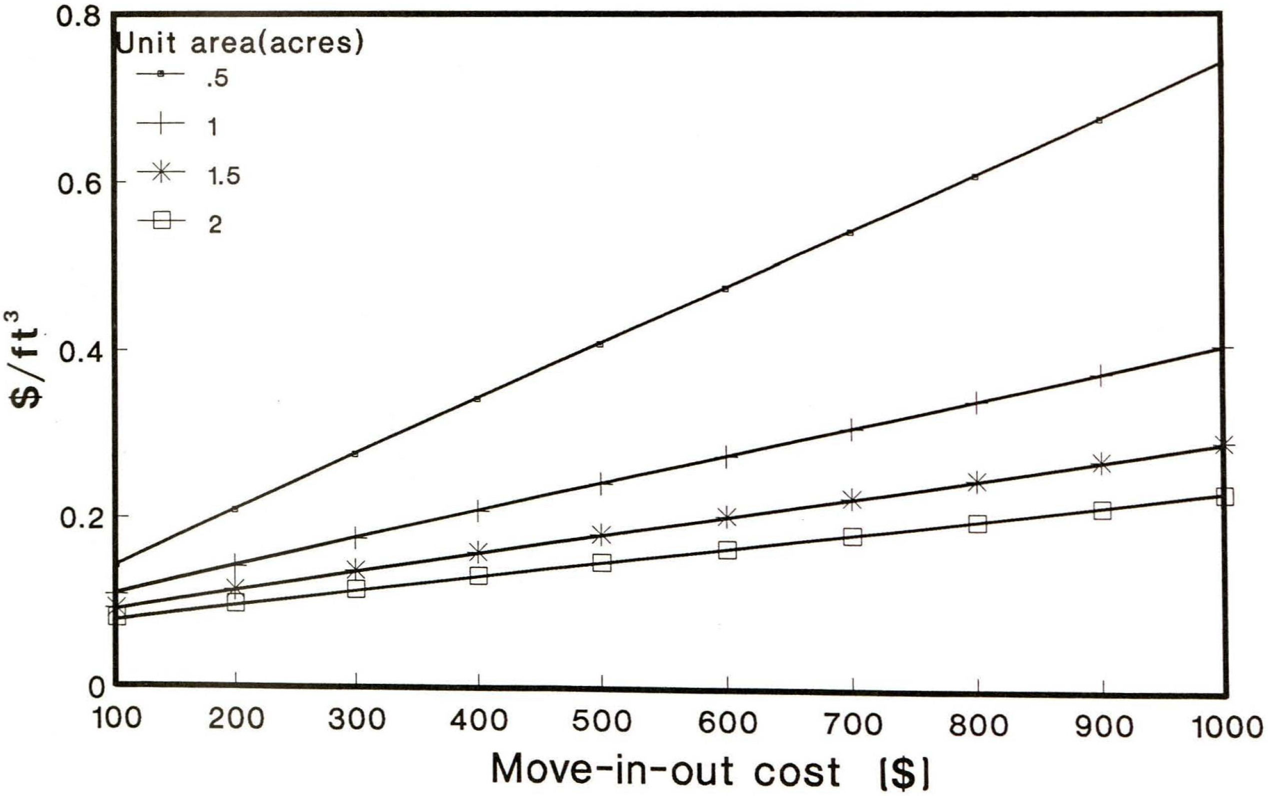


Figure 7.—Effects of harvest unit area and move-in-and-out costs on estimated total skidding and move costs. Conditions: slope distance = 1,073 feet, 4.4 logs/turn, 1.3 pulls/turn, and no prebunched logs.

CONSIDERATIONS FOR MANAGERS

Besides the prospect of removing overmature trees, insect and disease damage, blow down, ice damage, and other small pockets of timber, group-selection harvests offer other incentives: salvaging of valuable timber, maintaining esthetic and visual management objectives, wildlife management, and water-quality management. However, it is beyond the scope of this report to fully discuss all these management concerns. Supplemental research is under way to investigate and develop economic breakeven guidelines for group-selection harvests in a systems theory approach.

This study includes data from 14 group-selection harvest units that span typical Appalachian mixed hardwood sites. The skidding conditions and variables used to develop the production data cover the range of conditions normally encountered in ground-based logging of hardwoods. The prediction equation can be used to develop reliable estimates of stump-to-landing production rates that along with other associated costs, can be used to estimate group-selection harvesting costs. The results can be used in simulation programs or other ground-based logging models. There is additional research in the developing of breakeven guidelines and there is a computer program (GROUP-PC) to evaluate the efficiency of harvesting group-selection units. The ability to estimate the effect of several common skidding parameters on production and costs of skidding group-selection units, should make economical designs possible in future logging operations. This harvesting approach should result in balanced management of forest stands for fiber, wildlife, and other objectives.

LITERATURE CITED

Bell, R. D. 1989. Influences of varying stand harvest methods on timber harvesting costs in Southeastern Virginia hardwoods. Masters thesis. Virginia Polytechnic Institute and State University, Blacksburg, Virginia. 68 p.

Boucher, B. A.; Hall, O. F. 1989. Implementing group-selection in Appalachian hardwoods using economic guidelines. In: 7th Central Hardwoods Forest Conference; March 5-8, 1989; Carbondale, Illinois.

Brummel, K. R. 1992. The impact of group-selection silviculture on timber harvest cost in the southern Appalachians. Masters Thesis. Virginia Polytechnic Institute and State University, Blacksburg, Virginia. 145 p.

Erickson, M. D., Hassler, C. C., LeDoux, C. B. 1992. Group-selection harvests: Influence of group size on harvesting costs and productivity. In: Council on Forest Engineering 15th Annual Meeting; August 10-13, 1992; Hot Springs, Arizona.

LeDoux, C. B., Baumgras, J. E., Sherar, J., and Campbell, T. 1991. Production rates and costs of group-selection harvests with a Christy cable yarder. In: Proceedings of the Forestry and Environment - Engineering Solutions; June 5-6, 1991. Conference, ASAE: 75-84.

Minckler, L. S.; Woerheide, J. D. 1965. Reproduction of hardwoods: 10 years after cutting as affected by site and opening size. Journal of Forestry, 63(2):103-107.

Roach, B. A. 1974. What is selection cutting and how do you make it work? What is group-selection and where can it be used? Applied Forestry Research Institute, Miscellaneous Report No. 5. State University of New York, Syracuse, New York.

Smith, D. M. 1986. The practice of silviculture. Eighth ed. John Wiley and Sons, New York. 527 pp.

Profitability of Precommercially Thinning Oak Stump Sprouts

John P. Dwyer[1], Daniel C. Dey[2], and William B. Kurtz[2]

Abstract: Thinning oak stump sprouts to a single stem at an early age will increase diameter growth of the released stem. However, precommercial thinning represents a substantial investment which must be carried for many years before any returns are realized. We estimated the incremental gains in yield and the present net worth for five crop-tree release treatments of 5-year-old coppice sprouts in the southeastern Missouri Ozarks and compared them to the results from unthinned control plots. The treatments involved thinning 100, 150, 200, 250 and all clumps of sprouts on the plots to a single stem. All thinning treatments increased diameter growth and yield compared to the control, but at a 5 percent rate of return the control treatment produced the largest present net worth. We have concluded that based upon the growth response and timber price situations within the Ozark Region, precommercial thinning of oak stump sprouts is not an economical management practice.

INTRODUCTION

Regeneration of upland oak after a timber harvest is primarily from stump sprouts and advance reproduction. Stump sprouts which grow in clumps represent the fastest growing component of reproduction (Sander et al. 1984). Precommercial thinning of oak clumps to a single stem has been found to maximize diameter growth (Johnson and Godman 1983, Lamson 1983, Johnson and Rogers 1980), and increase the future value of residual trees (Allen and Marquis 1970).

However, the economic gains from thinning young stands must be weighed against the costs of carrying thinning investments over virtually the entire length of the rotation. Costs of precommercial thinning depend on residual stand density and method of thinning (i.e., area-wide versus crop tree). In this study the area-wide thin refers to the thinning of each and every clump of sprouts to a single stem over an entire acre. On the other hand, the crop- tree release involved thinning just 100, 150, 200, and 250 clumps per acre to release a single crop-tree sprout per clump while leaving the remaining clumps unthinned.

The objective of this study was to evaluate the economic returns for several thinning strategies applied to a 5-year- old oak stand.

DESCRIPTION AND HISTORY OF STUDY AREA

Located in southeastern Missouri in Butler County on the 7,000-ac University State Forest, the study site was classified by Fletcher and McDermott (1957) as a "flatwoods" that forms a transition zone between two larger physiographic provinces, the Ozark Plateau and the Mississippi Lowlands.

---

[1] The School of Natural Resources, University of Missouri, Columbia, MO 65211.

[2] Ontario Forest Research Institute, P.O. Box 969, 1235 Queen Street East, Sault Ste. Marie, Ontario, P6A 5N5.

The soil is a typic fragiudalf which contains a fragipan (28 to 33 in.) overlain by a loessal cap. Site index was estimated by Dwyer (1988) to be 69 ft (base age of 50 yrs) for scarlet oak.

Timber was harvested in the 1930s and 1940s. Harvest took place over several years leaving a stand composed of a few large non-merchantable trees and small clumps of stump sprouts. Later, fire and grazing created even-aged stands of primarily oak species. In the summer of 1953, the trees were 28- to 30-yrs-old and the stand was comprised principally of scarlet oak and black oak in the overstory and white oak, post oak, hickory and southern red oak in the understory. These species comprise the oak-hickory type which encompasses over 39 percent of the forested acreage in the Midwest (Merz 1979).

STUDY DESIGN

Three 1-ac plots were clearcut during July of 1953. Each plot was divided into four 0.25-acre subplots for a total of 12. A thinning and control (no-thin) treatment were randomly assigned to two of the subplots in each plot for a total of six. Within each thinned subplot 0.156 acres was treated. Surrounding the treated area was a 21.8-foot isolation strip. The remaining two subplots in each plot were initially designed for other treatments but subsequently were not used. In 1958, 5 years after clearcutting, a dominant sprout in each clump was selected for repeated measurements. Each and every clump was thinned to a single stem on the thinned subplots which corresponded to the area- wide treatment. The control subplot received no treatment.

At stand age 5, species, diameter of the parent stump, number of sprouts in the clump, and height of the dominant sprout were recorded. Diameter at breast height (dbh) of the study trees was measured to the nearest tenth-inch at ages 12-, 16-, 21-, 30- and 38-years. In 1991, at age 38, in addition to diameter, the total height of each tree was measured to the nearest foot, and cull percent was estimated using a sounding hammer and visual inspection. Growth and development of these coppice-regenerated oak stands have been reported by Mitchell et al. (1985) and Lowell et al. (1989). Data from this long-term study were used to evaluate the profitability of thinning in young oak stands.

DEVELOPMENT OF ALTERNATIVES

The investment analysis involved estimating the potential economic gain from releasing all, versus only selected crop trees within the stand, and comparing the results to the returns from the unthinned control. The crop-tree release treatments were not actually applied in the field. Rather, data from the long-term study were used to simulate the survival, growth and yield under these treatments. In the control treatment, a residual sprout was identified for future observation, but competing stems in the clump were not removed. However, all (both crop and non-crop) stems in the control treatment and crop-tree simulations were included in subsequent yield calculations. The area-wide thinning, which consisted of removing all but one stem on each and every stump across the area, resulted in 1,211 residual sprouts per acre.

Four residual crop-tree densities were believed to represent a reasonable range of management treatments; viz.; 100, 150, 200 and 250 trees per acre. Data from the unthinned plots were used for thinning simulation. At each of the four levels, a sprout was selected for release based primarily upon its height at age 5 years, and diameter of the stump and number of sprouts. Then, all smaller sprouts on the stump were "removed" in a simulated thinning.

STAND DEVELOPMENT MODELS

The Central States TWIGS (Belcher 1982) growth and yield simulator was used to project stand development for all treatments from stand age 21 to the end of rotation (60 and 70 yrs). TWIGS cannot predict stand development during the first 20 years. Therefore, early stand development was simulated by predicting the survival and growth of individual trees from stump sprouts using regeneration models developed for the Missouri Ozarks by Dey (1991). These models produce diameter distributions of both thinned and unthinned species- specific stands of stump sprouts from stand age 5 to 21.

The growth simulations from the regeneration model were used to generate a tree "list" at stand age 21 for each of the respective crop-tree thinning levels. While actual data were available for the no-thin and area-wide thinning treatments to age 38 years, no data were available on survival and growth of the crop-tree release treatments. As a result, the data set for the area-wide thinning treatment was used to construct the species-specific survival and growth models for these treatments to year 21. This list was then used as input for the TWIGS projection to final harvest at age 60 or 70.

Individual species were assigned species-specific site indices, which were computed (Carmean et al. 1989) for both the control and thinned plots using height data recorded at age 38 years. Gross volumes were adjusted to account for the estimated amount of cull present in the trees.

ECONOMIC ANALYSIS

The present net worth of each alternative was calculated using only those costs and revenues attributable to the alternative. Land and annual costs were excluded in order to examine thinning as a separate investment.

Six management regimes were compared: (1) no thin (control); (2) area-wide thin; and (3) the four crop-tree residual stand densities of 100, 150, 200, and 250 stems per acre. Final harvest was examined at age 60 and 70 years for each of the alternatives.

Stumpage prices used were the mean and high average prices (weighted by region) for 1991 and taken from *Missouri Timber Price Trends* quarterly market report. The high prices reflect a higher quality tree, indicated in parentheses below. The mean sawtimber stumpage prices used in this analysis were $91.35 ($140.13) per MBF (International "1/4-Inch Rule) for white oak; $87.86 ($133.54) per MBF for southern red oak, black and scarlet oak; $64.02 ($104.50) per MBF for post oak; and $43.32 ($74.33) for hickory. The prices for blocking ($6.50 per cord) and charcoalwood ($1.58 per cord) were estimated from an informal telephone survey of forestry consultants working in the Ozark region. Real stumpage prices were assumed to remain constant over time. Thinning costs (Table 1) were based upon actual thinning production records (276 stems cut per hour) for the thinned plots. The apparent relationship of the decrease in sprouts per clump (column 2) as the number of thinned clumps (column 1) increased, is because the desirable crop-tree sprouts occurred on stumps with a higher average number of sprouts. The average thinning cost per sprout was $0.0421 (1991 value). This cost includes labor, chainsaw maintenance and supplies, and travel to the plots (unpub. data, J.P. Dwyer, Univ Mo.-Columbia). Labor was valued at the current wage rate for University forest workers of $10.25 per hour which included fringe benefits.

Profitability was evaluated in terms of present net worth (PNW) expressed in dollars per acre. An underlying assumption was that intermediate funds would be reinvested for the life of the project at the required rate of return. The analysis was conducted using real discount rates of 3 and 5 percent.

RESULTS AND DISCUSSION

Stand characteristics at age 60- and 70-years are shown in Table 2 for all six management regimes. The area-wide thinning treatment showed a 26.4 and 20.4 percent increase in board foot volume over the unthinned stand at 60 and 70 years, respectively. Thinning stumps to a single

Table 1.—Total thinning costs for five clump thinning alternatives.

Clumps thinned (no.)	Sprouts per clump (no.)	Sprouts cut per acre (no.)	Total thinning[a] cost per acre ($)
100	9.1	913	38
150	8.4	1,254	53
200	7.2	1,450	61
250	6.9	1,714	72
1,211	4.4	5,301	223

[a] Based on a cost of $0.042 per sprout cut.

sprout significantly increased the diameter of the largest 100, 150, 200, and 250 crop trees per acre at age 38. "Largest" in this case (Figure 1) refers to the dominant sprout dbh at age 60. Average sprout dbh is based only on the crop trees for the crop tree release treatments. Analysis of variance was used to test for differences in diameter increase for trees in plots thinned to various crop-tree densities and control plots. At the $\alpha = 0.05$ level, diameter increase was significantly greater for the trees from all of the treated plots in comparison to the control plots.

Although stand volume at age 70 for the area-wide thinning treatment was 20 percent higher than for the control, and stumpage income was 21 percent higher, the PNW was lower by $214 per acre (Table 3). Benefits stemming from increased sawtimber yields attributable to thinning at age 5 are not sufficient to cover the area-wide precommercial thinning cost plus an annual accrual of 5.0 percent interest.

Crop-tree release offers the opportunity to reduce the cost of thinning for a 60-year-old stand. However, the 100-, 150-, 200-, and 250-crop-tree per acre alternatives did not yield a greater PNW than the unthinned treatment (Table 3). In addition, the 60-year-old stand had greater PNW values than the 70-year-old stand. This is due, in part, to the fact that the 60-year-old stand provides opportunities to harvest standing volume that otherwise would be lost to natural mortality after age 60. Also, the 60-year-old stand provides positive cash flows from the commercial harvest that occur earlier than the 70-year-old stand, thus increasing PNW. In fact, none of the alternatives in the 70-year management regime are as profitable as the unthinned alternative.

A sensitivity analysis was performed to evaluate the effect of two real discount rates (3 and 5 percent) and two alternative stumpage price scenarios on PNW. Results of this analysis (Table 4) show that the no-thin treatment generated the highest PNW regardless of which discount rate or stumpage price scenario was chosen. The PNWs of the crop-tree release treatments under the 3 percent/high price scenario were similar to the no-thin treatment. Profitability is improved for all crop-tree release treatments relative to the no-thin treatment when the high price scenario is considered. If, for example, the weighted mean sawtimber stumpage price were to rise to $140 and $181 per MBF for the 3 and 5 percent discount rates, respectively, then it would be a breakeven between the crop-tree 100 treatment and the no-thin treatment.

In reality, the PNWs would not be so similar because it would be reasonable to expect that the cost to release the crop trees would be higher because of the time to (1) select which stump to release and (2) decide which sprout to leave on the chosen stump. Additionally, some efficiency may be lost if size of sprouts were an overriding criterion for retention instead of optimum spacing. These two factors must be taken into account jointly in order to optimize growing space and yield the highest future profitability for the released sprouts.

Table 2.—Stand characteristics (on per-acre basis) of the six coppice regeneration management regimes at 60 and 70 years of age.

Crop-tree release treatment	Stocking (%)	Live trees (no.)	Basal area (ft^2)	Dbh (in.)	MAI (ft^3/yr)	Volume		
						Sawlog (mbf)[a]	Pulpwood (cords)	Residue (mft^3)
				60 years				
No thin	86	167	102	9.8	33.6	8.0	10.6	1.0
Area-wide	112	227	131	9.3	44.0	10.1	14.8	1.3
100	118	256	134	8.9	43.9	8.7	17.3	1.3
150	116	248	135	9.1	44.4	9.5	16.2	1.4
200	116	248	136	9.1	44.6	9.7	16.0	1.6
250	116	247	136	9.1	44.4	9.8	15.7	1.4
				70 years				
No thin	93	144	113	11.1	34.0	10.6	10.6	1.2
Area-wide	115	192	139	10.4	42.6	12.7	14.5	1.4
100	113	206	136	10.0	40.2	11.3	14.9	1.4
150	112	198	136	10.2	40.7	11.9	14.4	1.4
200	112	199	136	10.2	40.8	11.9	14.3	1.4
250	112	198	136	10.2	40.6	11.5	14.9	1.4

[a] Volume in International 1/4-Inch

CONCLUSION

The cost of thinning young oak coppice sprouts cannot be overcome by selecting stems from clumps which exhibit dominant characteristics. Thinning the best 100, 150, 200, or 250 crop trees per acre was not found to be as profitable as the no-thin treatment on a 60-year rotation. For the longer rotation, the cost of precommercial thinning exceeds the discounted increases in final harvest revenues. Evaluating the profitability of thinning oak sprouts at a 3 percent interest rate and under a high price scenario did not yield increases sufficiently high to warrant a crop-tree release treatment.

LITERATURE CITED

Allen, R.H., and D.A. Marquis. 1970. Effect of thinning on height and diameter growth of oak and yellow-poplar saplings. USDA For. Serv. Res. Pap. NE-173. 11 p.

Belcher, D.M. 1982. TWIGS: The Woodsman's Ideal Growth Projection System. P. 70-95 in Microcomputers: A new tool for foresters. SAF Publ. 82-05.

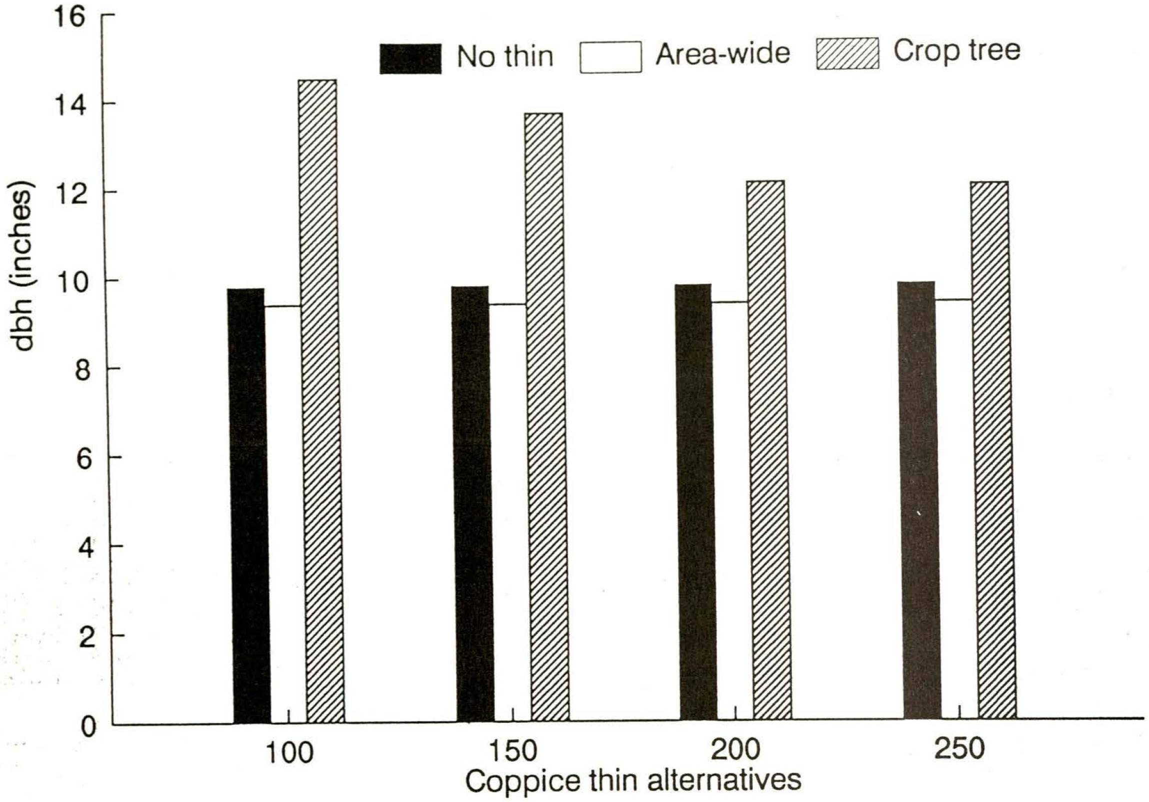


Figure 1.—Average sprout dbh of no thin, area-wide, and crop tree alternatives at age 60 years.

Carmean, W.H., J.T. Hahn, and R.D. Jacobs. 1989. Site index curves for forest species in the eastern United States. USDA For. Serv. Gen. Tech. Rep. NC-128. 142 p.

Dey, D.C. 1991. A comprehensive Ozark regenerator. PhD. diss. Univ. Mo, Columbia. 283 p.

Dwyer, J.P. 1988. Evaluation of the long-term silvicultural and economic effects of thinning and pruning treatments on a scarlet and black oak timber stand in southeastern Missouri. PhD. diss. Univ. Mo, Columbia. 255 p.

Fletcher, P.W., and R.E. McDermott. 1957. Moisture depletion by forest cover on a seasonally saturated Ozark ridge soil. Proc. of Soc. Am. Soil Sci. 21:547-550.

Johnson, P.S., and R.M. Godman. 1983. Precommercial thinning of oak, basswood, and red maple sprout clumps. P.124-139 in Proc. Silviculture of established stands in North Central Forests. SAF Region V Tech. Conf. Duluth, MN.

Johnson, P.S., and R. Rogers. 1980. Predicting growth of individual stems within northern red oak sprout clumps. P.420-439 in Proc. Third Central Hardwood Forest Conference. Columbia, MO.

Lamson, N.I. 1983. Precommercial thinning increases diameter growth of Appalachian hardwood stump sprouts. So. J. Appl. For. 7:93-97.

Table 3.—Investment performance of the crop-tree release thinning levels for coppice-regenerated stands at a 5% real discount rate and stand ages 60 and 70.

Management alternative	**Stumpage income**	**Present value**		
		Cost	**Revenue**	**PNW**
	($ per acre)			
		60 years		
No thin	788	-0-	54	54
Area-wide	1,004	223	69	-154
Crop-tree 100	900	38	61	23
Crop-tree 150	962	53	66	13
Crop-tree 200	979	61	67	6
Crop-tree 250	983	72	67	-5
		70 years		
No thin	1,018	-0-	43	43
Area-wide	1,236	223	52	-171
Crop-tree 100	1,115	38	47	9
Crop-tree 150	1,157	53	49	-4
Crop-tree 200	1,164	61	49	-12
Crop-tree 250	1,130	72	47	-25

Lowell, K.E., H.E. Garrett, and R.J. Mitchell. 1989. Early thinning can improve your stand of coppice-regenerated oak. P.53-58 in Proc. Seventh Central Hardwood Forest Conference. Carbondale, IL.

Merz, R.W. 1979. Forest atlas of the Midwest. USDA For. Serv., North Central For. Exp. Stn., St. Paul, MN. 48 p.

Mitchell, R.J., R.A. Musbach, K.E. Lowell, H.E. Garrett, and G.S. Cox. 1985. Thinning a coppice regenerated oak-hickory stand: Thirty years of growth and development. P.19-24 in Proc. Fifth Central Hardwood Forest Conference. Urbana, IL.

Sander, I.L., P.S. Johnson, and R. Rogers. 1984. Evaluating oak advance reproduction in the Missouri Ozarks. USDA For. Serv. Res. Pap. NC-251. 16 p.

Table 4.—Sensitivity analysis for alternative thinning treatments for coppice regenerated 60-year-old oak stands.

Management alternative	3% discount rate		5% discount rate	
	Mean price	High price	Mean price	High price
	(PNW - $ per acre)			
No-thin	155	227	54	79
Area-wide	-26	65	-154	-123
Crop-tree 100	139	217	23	50
Crop-tree 150	136	222	13	43
Crop-tree 200	132	219	6	36
Crop-tree 250	121	209	-5	26

Relative Price Trends for Hardwood Stumpage, Sawlogs, and Lumber in Ohio

John E. Baumgras and William G. Luppold[1]

Abstract: During the 1980's, the hardwood lumber industry experienced a rapidly changing domestic and international hardwood product market. These changes have significantly affected prices of hardwood lumber, and subsequently affected prices of hardwood sawlogs and stumpage. To illustrate these changes, this paper examines deflated prices and price trends for hardwood lumber, and Ohio sawlogs and stumpage from 1975 to 1991. Differences between log price trends, and the trends in stumpage and lumber prices also are examined. Results show increasing real prices for red and white oak sawlogs and red oak lumber; high-quality sawlogs showed the largest gains. Real prices of sawlogs and lumber declined for non-select species such as yellow-poplar and hard maple. The analysis of price relationships also indicated that the relative gains in red oak and yellow-poplar stumpage prices exceeded those of sawlog prices. For red oak, sawlog prices also increased at a greater rate than lumber prices. These results indicate that stumpage prices have increased because of transferred efficiencies in milling and harvesting, as well as the growing domestic and international demand for high-quality oak lumber and veneer.

INTRODUCTION

Since 1975 the hardwood lumber market has experienced considerable change. Although hardwood lumber production is still cyclical, the trend for eastern hardwood production has been upward. Between 1976 and 1991, hardwood lumber lumber production increased by more than 3.5 billion board feet (Luppold and Dempsey 1989); the bulk of this growth occurred in the mid 1980's. The forces behind this growth are increased prices resulting from increased domestic and international demands (Luppold 1991). A disproportionate amount of this increased demand was for higher quality oak, ash, cherry, and hard maple lumber.

The strong market reflecting increased demand for higher quality hardwoods of the more select species caused many of the larger hardwood sawmills to purchase new equipment capable of cutting large volumes of higher quality logs. This change caused greater demands for higher quality logs and stumpage that were already in relatively low supply. As a result, prices of higher quality logs and stumpage of the select species increased at a much greater rate than the price of lower quality logs and logs of non-select species.

The purpose of this paper is to examine the change in log, stumpage, and lumber prices over the last 15 years, and to contrast changes in different species and grades of hardwood logs. This paper will also demonstrate how changing log and stumpage prices have reduced sawmill operating margins, forcing these firms to become even more efficient.

---

[1] Research Forest Products Technologist, USDA Forest Service, Northeastern Forest Experiment Station, Morgantown, WV 26505, and Economist and Project Leader, USDA Forest Service, Northeastern Forest Experiment Station, Princeton, WV 24740.

METHODS

The price series analyzed include stumpage prices and delivered log prices reported for Ohio from 1975 to 1991 (Ohio Agric. Stat. Serv. 1975-91), and hardwood lumber prices reported in the Hardwood Market Report (Lemsky 1975-91). The four log grade designations used in this report and the corresponding quality and size criteria include; prime logs (USFS grade 1, scaling diameter ≥ 16 inches), grade 1 logs (USFS grade 1, scaling diaemter 13-15 inches), grade 2 logs (USFS grade 2, scaling diameter ≥ 12 inches), grade 3 (USFS grade 3, scaling diameter ≥ 8 inches).

To compare real prices, reported nominal prices were deflated with the Producer Price Index for all commodities (1982=100). To compare and plot real price trends for selected price series, ordinary least squares regression analysis was used to estimate the average annual compounded rate of change (r) in prices using the log-linear equation $Y = b_0+b_1X$; where Y = the natural logarithm of real price, X = year, and r = antilog (b_1)-1 (de Steiguer and others 1989).

Ratios of indexed prices were calculated to relate real price trends for stumpage and lumber to the real price trend for delivered logs. Real prices of stumpage, logs, and lumber were indexed so that real prices for 1975 = 100. The indexed lumber and stumpage prices for each year in the series were then divided by the indexed log price for that year, and multiplied by 100. Index ratios greater than 100 indicate that prices for stumpage or lumber increased proportionately more than log price, or decreased less when all prices were declining. Indexed ratios less than 100 indicate that prices for lumber or stumpage increased proportionately less than log prices, or decreased more when all real prices were declining. Log prices represent grade 1 logs. Lumber prices represent No. 1 common lumber.

RESULTS

Comparing log price trends reveals important differences in the markets for specific tree species and demonstrates the cyclical nature of the hardwood log market (Figure 1). The real prices of grade 1 red oak and white oak logs significantly outpaced the rate of inflation from 1975 to 1991, with real prices increasing at an average annual rate of 2.6 percent for red oak and 1.5 percent for white oak. These real growth rates reflect the strong domestic and international market for these two species. Weak markets for hard maple and yellow-poplar contributed to the extended decline in real prices that averaged -2.0 percent per year for these two species. The net result of these diverging price trends is a growing spread in real prices between select and non select species, from $34/Mbf or less in 1975, to approximately $165/Mbf in 1991. It should be noted that the current market indicates improved demand for yellow-poplar and hard maple, resulting in recent real price gains.

The cyclical nature of the hardwood market, a response to general economic conditions and international demand, is evident from the peaks and valleys in the price trends. Real prices increased from 1975 to 1979, declined from 1979 to 1982, made strong gains from 1982 to 1988-89, and then showed a modest decline (Figure 1). These cyclical affects were most pronounced for oak logs and had minor effects on the declining prices of hard maple and yellow-poplar.

Log price trends are also affected by log quality. The real prices of grade 2 or better red oak sawlogs have increased, while grade 3 sawlog prices have decreased slightly (Figure 2). The very strong growth rates in prime log prices reflect the increased emphasis on quality in both the domestic and international lumber markets. This demand for quality lumber also has increased the price spreads between log grades of red oak sawlogs and amplified the magnitude of cyclical variations in the real prices of grade 1 and prime red oak sawlogs. The modest downward trend in grade 3 prices indicates a weak market for low-quality red oak logs and lumber. Due to the weak market for yellow-poplar, the prices of all log grades have cycled downward with very little change in the price spreads between log grades (Figure 3).

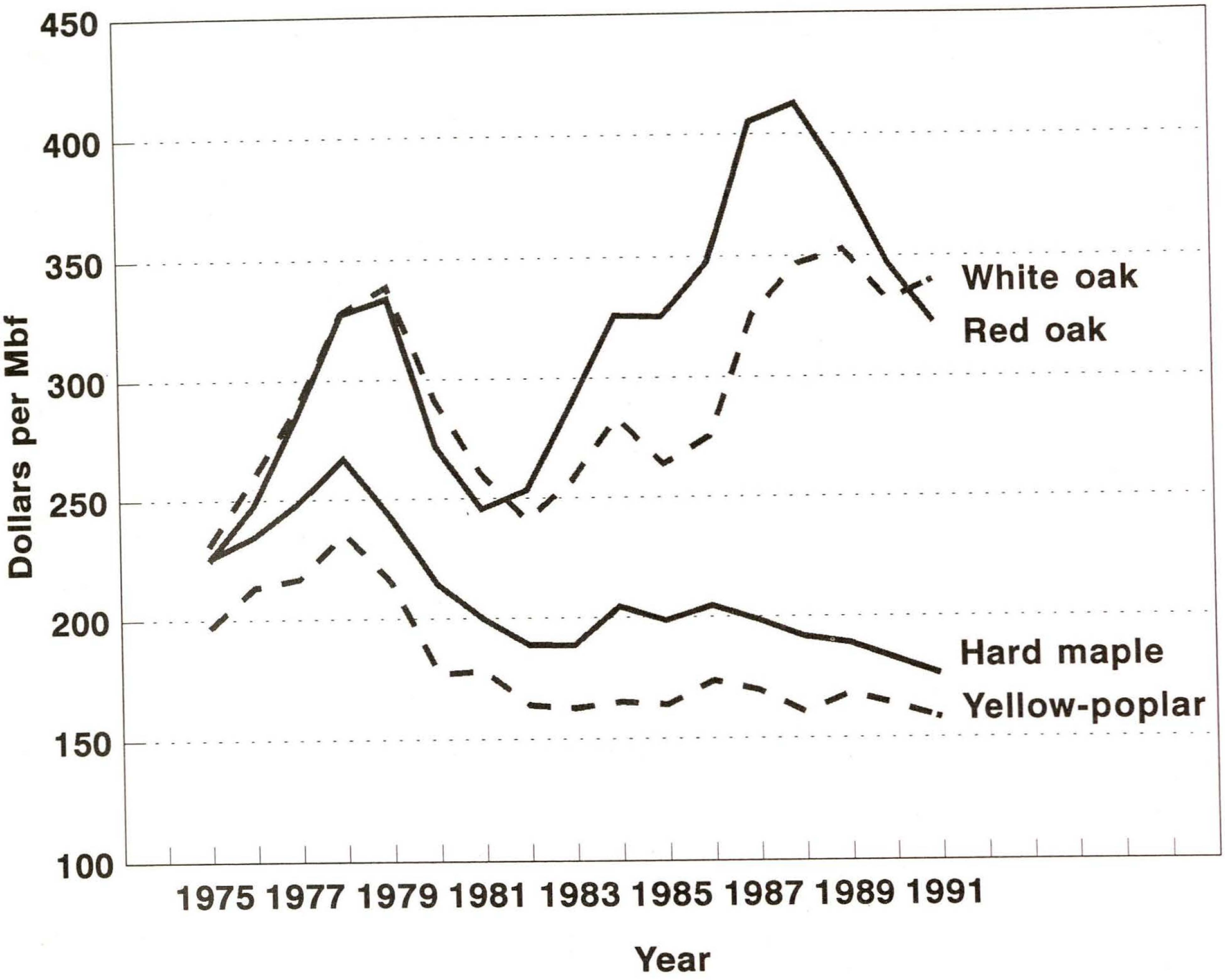


Figure 1.—Real prices of Ohio white oak, red oak, hard maple, and yellow-poplar grade 1 logs, 1975-91 (in 1982 dollars).

Comparing real stumpage prices for red oak and yellow-poplar further defines the differences in the market for select and non-select species (Figure 4). These stumpage price trends are similar, but not identical, to the log price trends shown in figure 1. The average annual rate of increase in real red oak stumpage price (4.8 percent) exceeds the rates for all grades of red oak sawlogs. Whereas the price of all grades of yellow-poplar sawlogs has generally declined from 1975 to 1991, yellow-poplar stumpage price showed a very small increase (0.6 percent per year). Diverging price trends also increased the price spread between red oak and yellow-poplar stumpage from approximately $25/Mbf in 1975, to more than $100/Mbf in 1991 (Figure 4).

Prices of No. 1 common lumber show the now familar upward trend for red oak and downward trend for yellow-poplar (Figure 5). However, the 1.2 percent average rate of increase in the real price of No. 1 common red oak lumber is less than the rate of increase for red oak stumpage (4.8 percent), prime logs (3.2 percent), and grade 1 logs (2.6 percent). For No. 1 common yellow-poplar lumber, real prices declined at an average annual rate of -1.8 percent whereas stumpage prices increased 0.6 percent per year. However, this rate of decline is very similar to the real price trends for yellow-poplar saw logs.

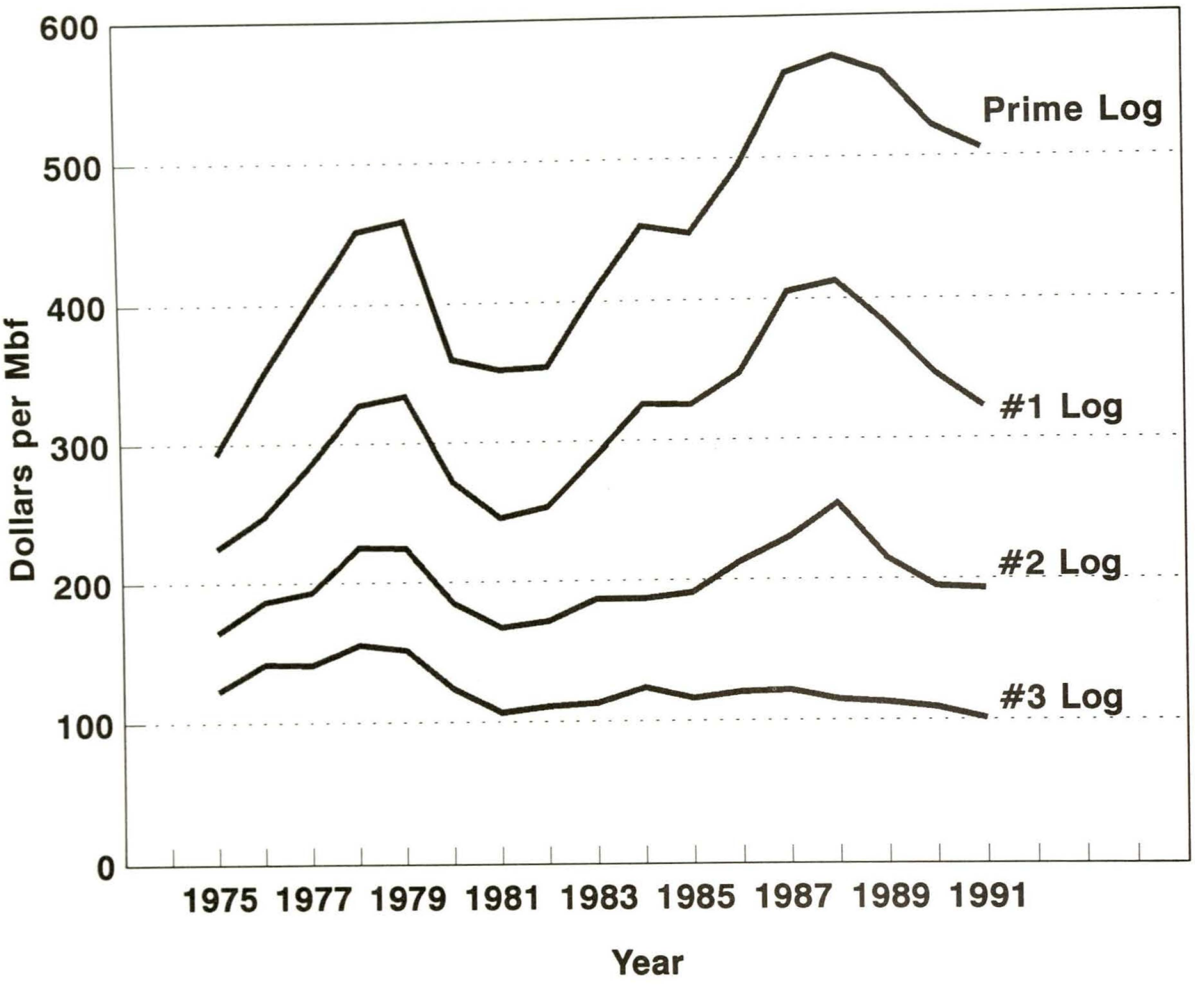


Figure 2.—Real prices of Ohio red oak logs, 1975-91 (in 1982 dollars).

The ratios of indexed stumpage and lumber prices to indexed log prices indicate growth of stumpage and lumber prices relative to the growth rate of log prices. Plotting these ratios and trends illustrates important changes in the hardwood market. For red oak, all three real price series indicate positive growth in real terms. However, the stumpage to log price ratios greater than 100 indicate that stumpage prices have increased faster than log prices since 1980-81 (Figure 6). Even though real prices declined from 1980-83, stumpage prices declined proportionately less than log prices. Conversely, lumber to log price ratios less than 100 indicate that lumber prices generally have not kept pace with log prices since 1980-81. Although both ratios began converging in 1989-90, the lumber to log price ratio has converged more than the stumpage to log price ratio.

The trend in the stumpage price to log price ratio for yellow-poplar is similar to that for red oak (Figure 7). Although yellow-poplar stumpage prices increased very little, log prices have declined. Part of the increase in the stumpage prices relative to log and lumber prices is due to the residual effect of the overall stumpage market. The stumpage price of all species is increasing faster than log and lumber prices because of market expectations and transferred efficiencies in harvesting and milling. Although lumber prices fluctuate more than log prices, yellow-poplar log and lumber prices show similar declines in real prices and are tracking together (Figure 7).

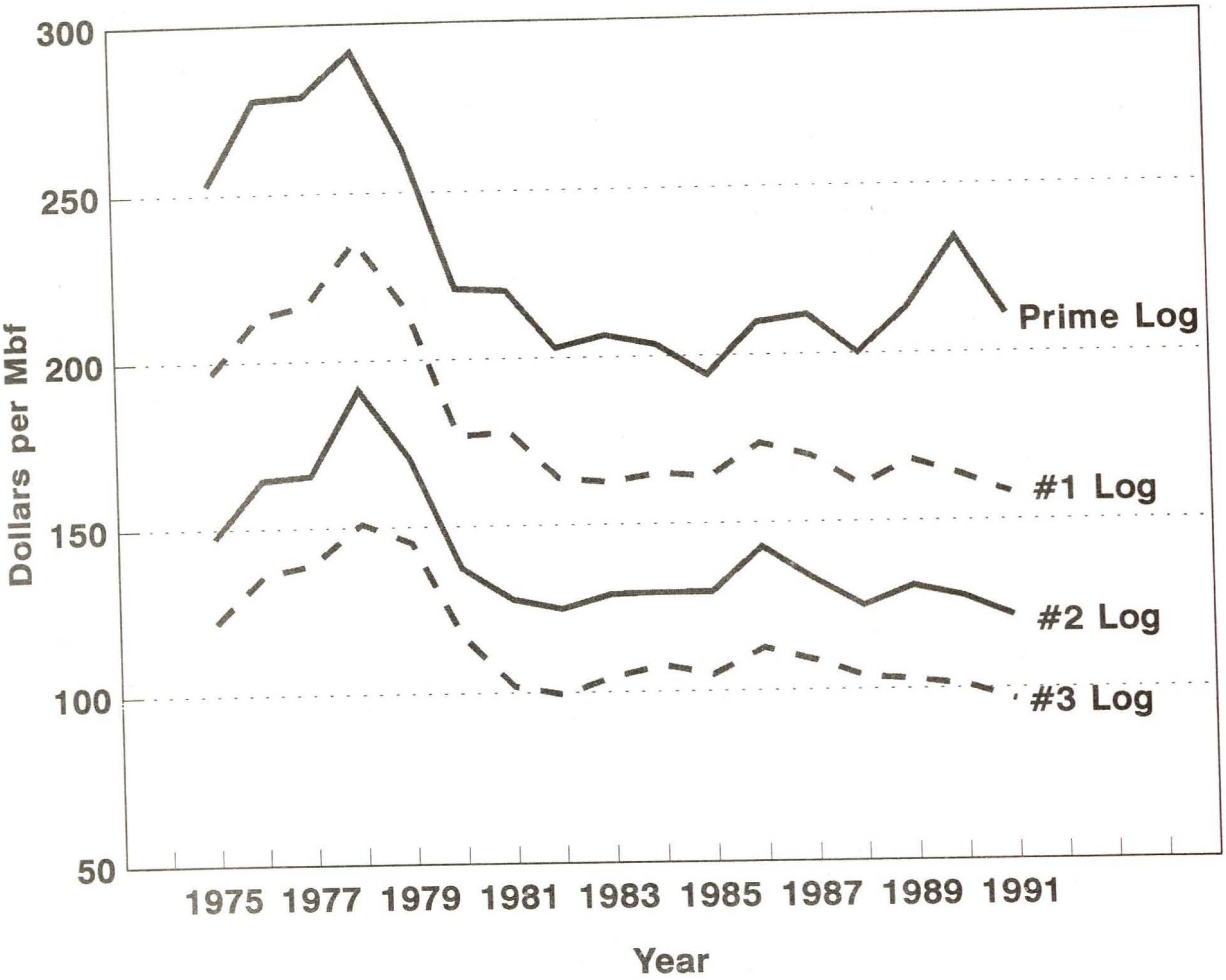


Figure 3.—Real prices of Ohio yellow-poplar logs, 1975-91 (in 1982 dollars).

DISCUSSION

The early 1980's marked the beginning of very strong domestic and international markets for high-quality hardwoods in applications such as millwork. Lumber consumption trends from 1977 to 1991 indicate large increases in the volume of red and white oak lumber going into millwork, kitchen cabinets, and flooring and a 250 percent increase in lumber exports (Dempsy and Luppold 1992). This increased demand and competition for quality lumber, together with improved efficiency in harvesting and sawmilling, have transferred down to stumpage prices. Relatively large gains in the oak veneer market also have helped move the stumpage market faster than the sawlog market. The net result is lower margins for timber harvesting and transportation—with stumpage prices increasing faster than log prices—and lower margins for milling—with log prices increasing faster than lumber prices.

The decreasing margin between hardwood sawlog and stumpage prices is not unique to Ohio or the 1975-91 time frame of this analysis. Remington and Dennis (1986) reported declining real harvesting costs (roadside prices minus stumpage prices) for hardwood sawtimber in New Hampshire from 1964-83. However, stumpage and log price trends do exhibit distinct regional differences.

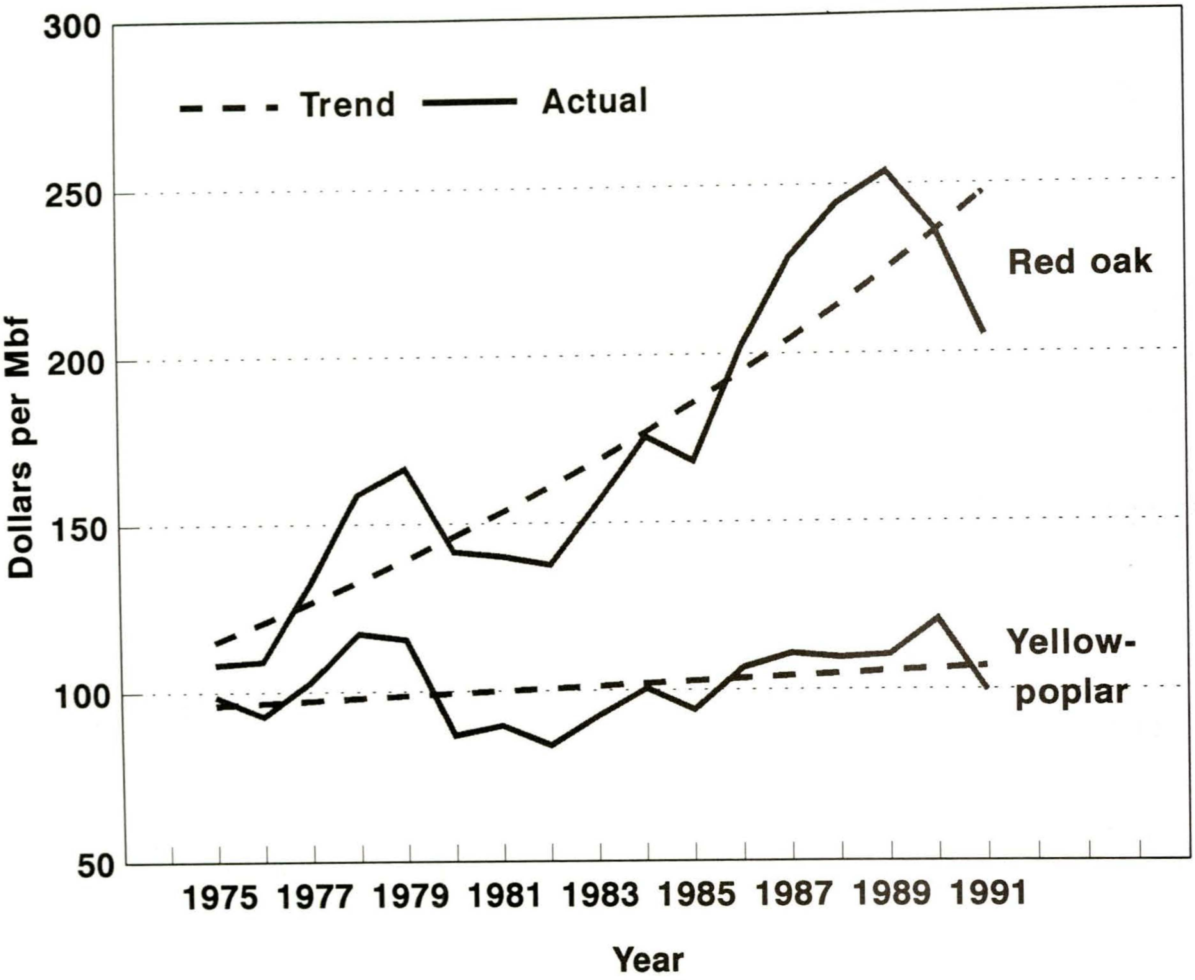


Figure 4.—Real prices and real price trends of Ohio red oak and yellow-poplar stumpage, 1975-91 (in 1982 dollars).

From 1972-83, real prices of hard maple stumpage and sawlogs showed positive price trends in New Hampshire (Remington and Dennis 1986); versus declining trends in Ohio. A study of price trends for hardwood stumpage and delivered log prices between 1976 and 1988, indicate declining real prices for all hardwood species in five southern Appalachian states (de Steiguer and others 1989).

The relatively scarce physical supply of high-quality sawlogs also contributes to the gains in real prices for select species and price spreads between log grades of all species. Forest survey results reported for Ohio show the percentage of sawlog volume in grade 1 logs ranging from a high of 27 percent for red oak, to a low of 10 percent for hard maple (Dennis and Birch 1981). To meet the growing demand for sawlogs, Ohio sawmills have increasingly relied on logs imported from neighboring states. The volume of sawlogs imported, mostly oak, increased from 20 million board feet in 1978, to 62.3 million board feet in 1983 (Widman and Long 1986).

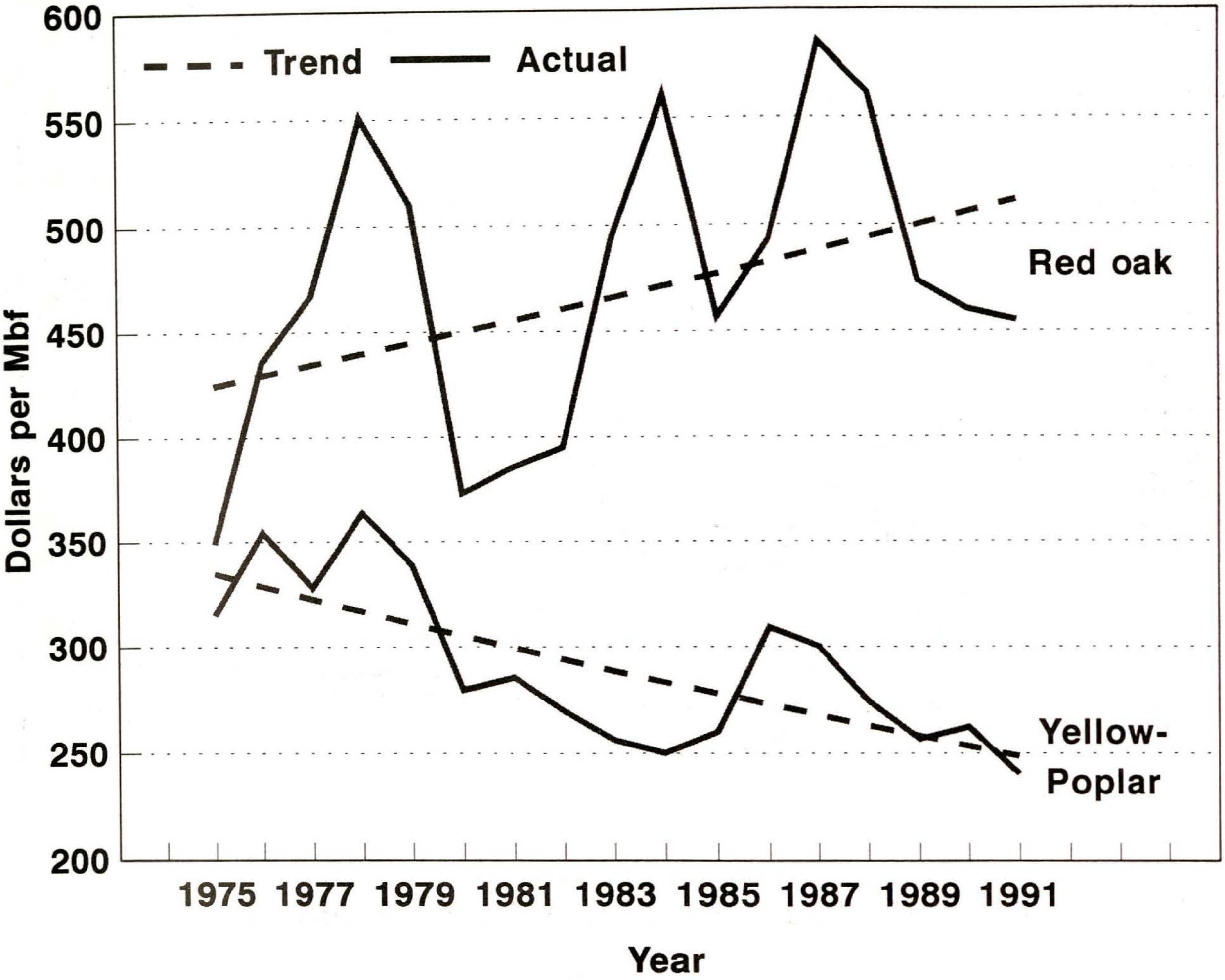


Figure 5.—Real prices and real price trends of No. 1 Common red oak and yellow-poplar lumber, 1975-91 (in 1982 dollars).

LITERATURE CITED

Dempsey, G. P. and W. G. Luppold. 1992. The state of hardwood lumber markets. North. Logger and Timber Proc. 40(10):22-24.

Dennis, P. and T. Birch. 1981. Forest Statistics for Ohio - 1979. USDA For. Serv. Resour. Bull. NE-68. 79 p.

de Steiguer, J. E., L. W. Hayden, D. L. Holley, Jr., W. G. Luppold, W. G. Martin, D. H. Newman, and R. M. Sheffield. 1989. Southern Appalachian timber study. USDA For. Serv. Gen. Tech. Rep. SE-56. 45 p.

Lemsky, A. 1975-1991. Hardwood market report. Memphis, TN: 1418 Madison Ave.

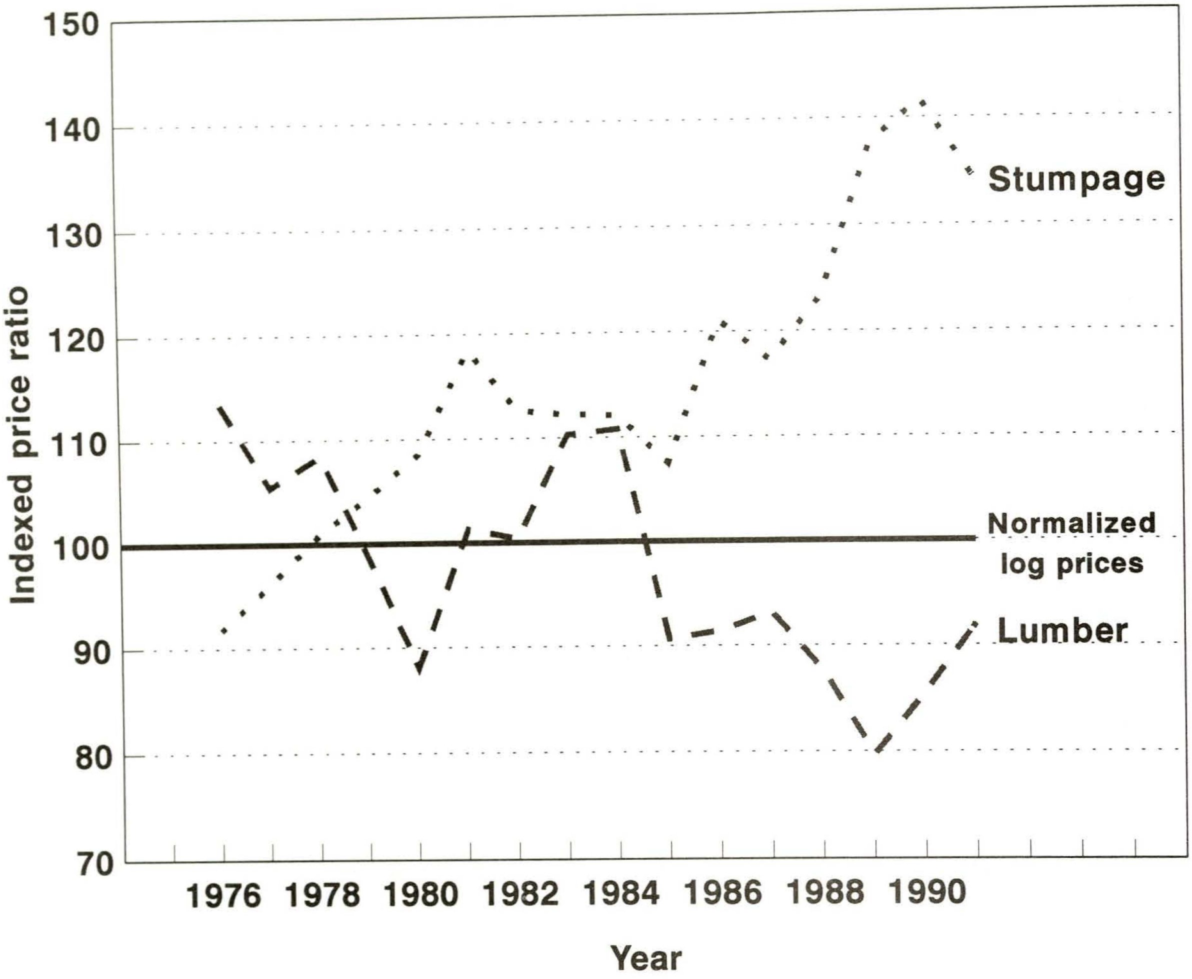


Figure 6.—Ratios of indexed prices of Ohio red oak stumpage and No. 1 Common red oak lumber, normalized on grade 1 log prices, 1975-91.

Luppold, W. G. 1991. Hardwood lumber demands in the 1990's. In: Facing uncertain futures and changing roles in the 1990's: 19th annual hardwood symposium of the Hardwood Research Council; 1991 March 10-12. Starkville, MS: Mississippi State University: 57-63.

Luppold, W. G. and G. P. Dempsey. 1989. New estimates of central and eastern U.S. hardwood lumber production. North. J. Appl. For. 6(3):120-123.

Ohio Agriculture Statistics Service. 1975-1991. Ohio timber prices. Ohio Agric. Stat. Serv., Columbus.

Remington, S. B. and D. F. Dennis. 1986. New Hampshire's stumpage and roadside prices: Characteristics and trends. USDA For. Serv. Res. Note NE-332. 8 p.

Widman, R. H. and M. Long. 1986. Ohio timber products output — 1983. USDA For. Serv. Resour. Bull. NE-95. 29 p.

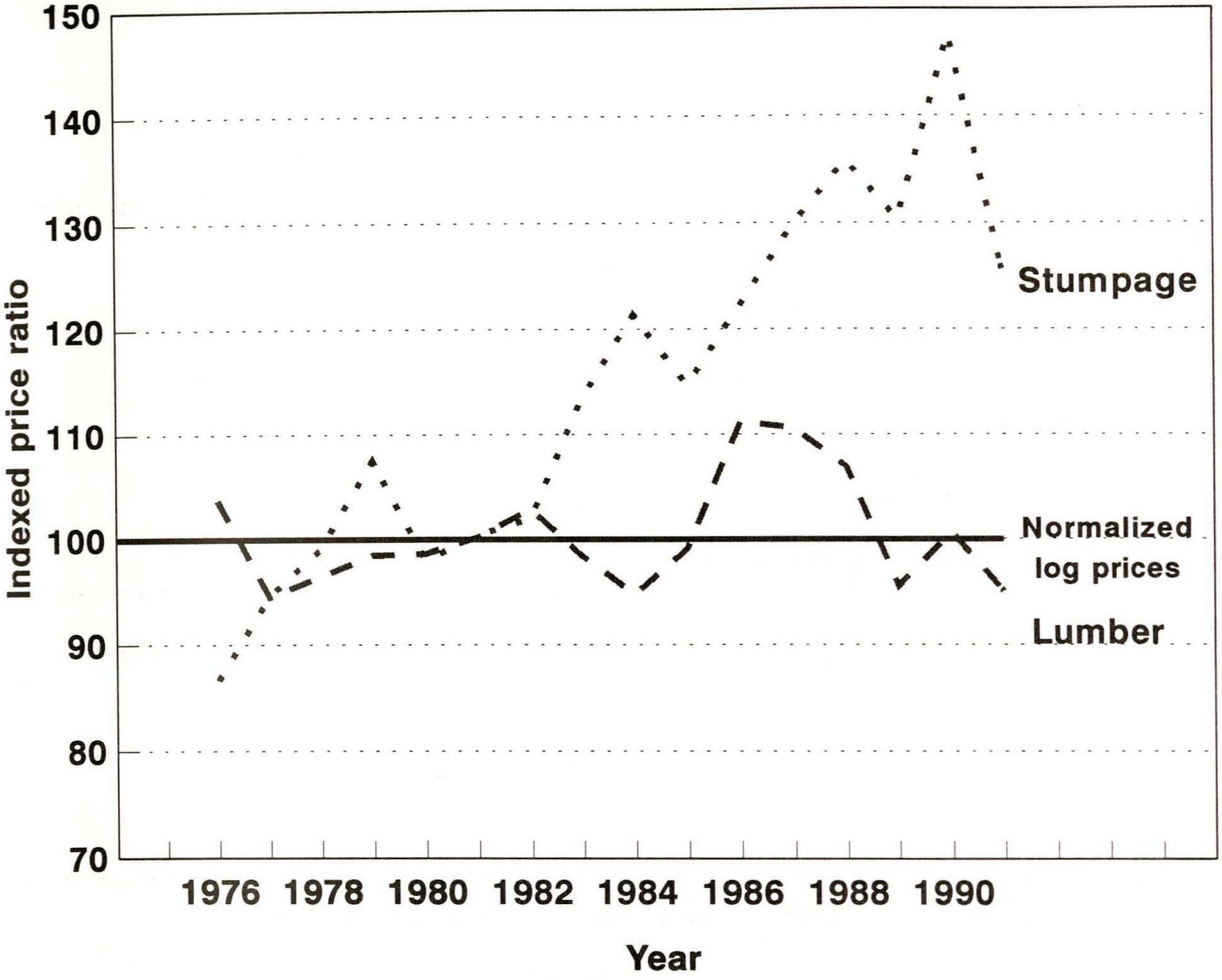


Figure 7.—Ratios of indexed prices of Ohio yellow-poplar stumpage and No. 1 Common yellow-poplar lumber, normalized on grade 1 log prices, 1975-91.

Public Land Use and Potential Impact on Missouri's Forest Products Industry

Bruce E. Cutter and William B. Kurtz[1]

Abstract: Management of public lands impacts Missouri's forest products industry in a significant manner, particularly in rural areas. In 1989, some 1,340 firms were involved in the forest products industry, employing approximately 29,200 workers. Total value-added in 1989 was in excess of $1 billion and the industry's activity generated another $400 million in related industrial activivty. In 1988, the most recent year for which data is available, public lands provided 19.7% of the sawtimber harvested statewide. The Eastern Ozarks is the most heavily forested region in Missouri, has a primarily rural population and contains some 42% of the loggers, 45% of the sawmills and drykilns, 32% of the pallet plants, and 34% of the other primary producers. This region also has the highest amounts of public forestland in the state. It would appear that alteration of current public land forest resource management strategies could have significant impacts on local economies in regions such as the Eastern Ozarks, an area that provides 40% of the state's sawtimber supply.

The forest products industry in Missouri is a valuable contributor to the economic base of the state. Furthermore, public lands impact that industry in a significant manner, particularly in rural areas. A survey of the forest products industry in 1989 (Trokey et al. 1991) and the recently completed USDA Forest Service Forest Survey of Missouri provided us the information from which input may be gained regarding this relationship.

The tangible and intangible benefits that accrue to landowners and the state from hunting and fishing, recreation, or mineral exploitation are real and have economic importance that must not be overlooked although estimation of their values are beyond the scope of this paper. To illustrate the magnitude of these benefits, an editorial in the June, 1991 *Missouri Conservationist* indicated that in 1985, hunters, anglers, hikers, canoers, and other non-consumptive users spent $1.5 billion, supported another $2.8 billion in business activity and provided 57,000 jobs in Missouri.

ECONOMIC CONTRIBUTION

In 1989, some 1,340 firms were involved in the forest products industry, employing approximately 29,200 workers (Trokey et al., 1991). Loggers comprised the largest number of firms, while secondary manufacturing (furniture, millwork, etc.) employed the greatest number of workers. Of the direct manufacturers, the greatest number were sawmills. Total value-added in 1989 by the forest products industry, exclusive of the paper products industry, was $1.06 billion. If information on the paper products industry is included from the 1987 Census of Manufactures, the level of value-added increases to $2.3 billion and the total number of employees increases by some 12,600 to approximately 41,800 employees. This output causes another $400 million in additional business activity in other non-forest sectors of the state's economy.

---

[1] Associate Professor and Professor of Forestry, The School of Natural Resources, University of Missouri-Columbia, Columbia, Missouri 65211

The forest products industry in Missouri characterizes many other industries whose production activities generate additional business activity and hence earnings in other sectors of the economy. This is termed the "multiplier effect." Output multipliers—the additional business activity on other sectors due to a $1 increase in sales in a given sector—range from 1.1 to 1.5 for the Missouri forest products industry. These multipliers vary from region to region in the state and from sector to sector in the industry. By their very nature, the smallest multipliers are in logging and charcoal production while the largest are in secondary manufacturing, sawmilling and drying, wood preservation, and pallet production (Devino and Braschler, 1991).

MISSOURI'S TIMBER RESOURCE

Five USDA Forest Service Survey Units have been defined in Missouri based on relative homogeneity of timber resource: Prairie, Riverborder, Northwest Ozarks, Southwest Ozarks, and Eastern Ozarks (Figure 1). Table 1 shows the amounts of commercial timberland in these survey units by ownership class. Commercial timberland is defined as forest land that is producing or is capable of producing in excess of 20 cubic feet per acre per year under natural conditions. In addition, there are some other forested lands which are either (a) not capable of producing 20 cf/A/yr [usually because of site conditions] or (b) forest lands withdrawn from timber utilization through statute, administrative regulation, or designation (Table 2). By like token, not all land classified as commercial timberland is available for harvest either. This is particularly true in the private ownerships where landowner objectives and attitudes vary widely (Trokey 1981).

Table 1.—Commercial Timberland in Missouri by Survey Unit and Ownership Class. (Thousands of acres) (from Hahn and Spencer, 1991)

Survey Unit	Land area	Timber-land	Nat'l Forest	Misc. Federal	State	Other Public	Forest industry	Private[a]
Eastern Ozarks	6,135.5	4,110.0	873.8	41.1	197.1	—	184.3	2,813.7
Northwest Ozarks	4,993.8	2,169.6	135.1	102.0	26.4	2.9	—	1,903.2
Prairie	19,541.2	2,500.3	——	77.6	53.7	25.8	—	2,343.2
Riverborder	8,019.3	2,092.7	18.0	8.9	87.2	8.4	7.7	1,962.5
Southwest Ozarks	5,435.0	2,498.2	294.0	16.7	38.1	5.1	30.4	2,113.9
Total	44,124.9	13,370.8	1,320.9	246.3	402.5	42.5	222.4	11,136.5

[a] This category includes land owned by farmers, miscellaneous private corporations, and miscellaneous private individuals.

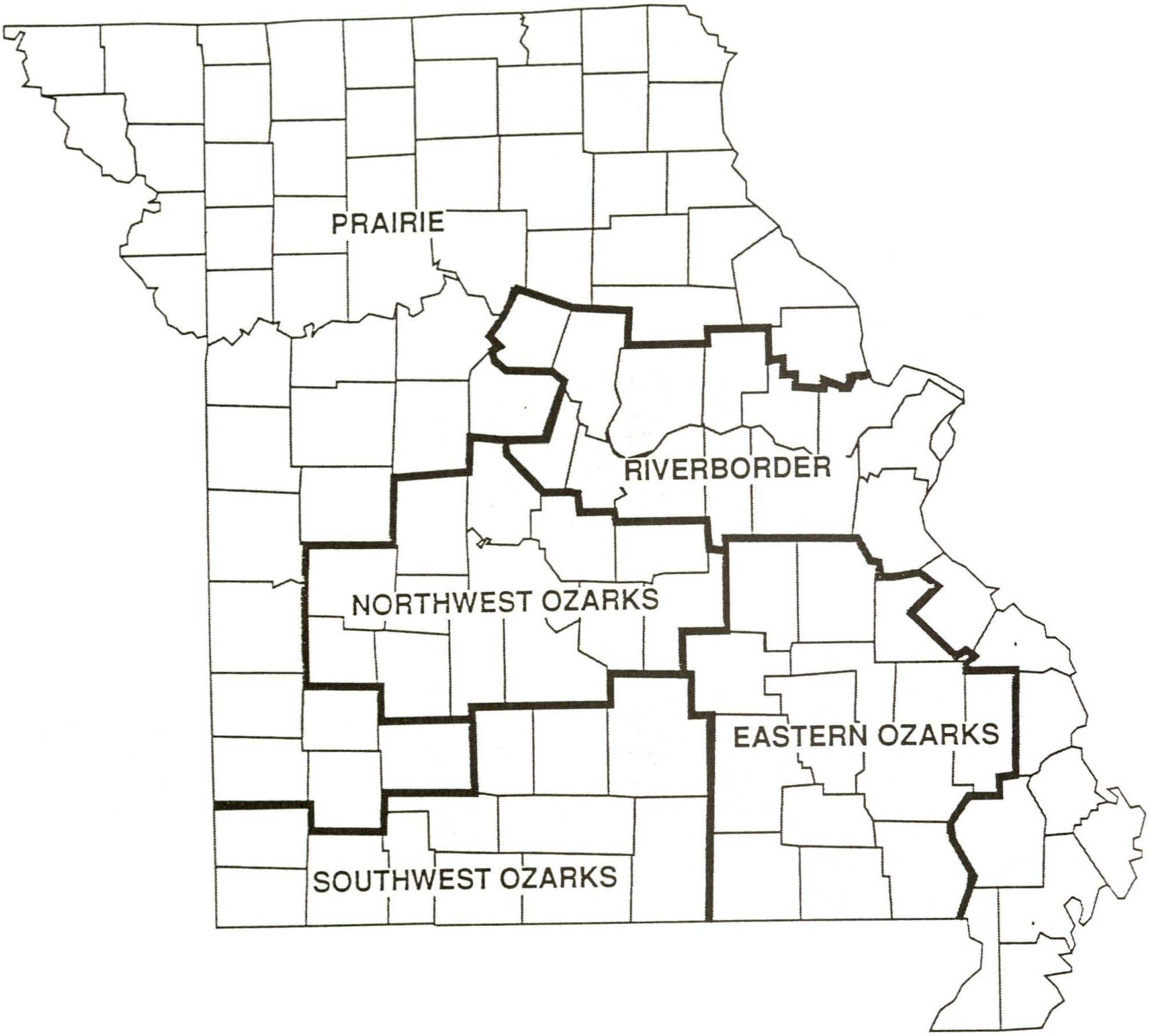

PRAIRIE
RIVERBORDER
NORTHWEST OZARKS
EASTERN OZARKS
SOUTHWEST OZARKS

Figure 1.—Forest Service Survey Units for Missouri.

Table 2.—Forest land in Missouri. (Thousands of acres) (from Hahn and Spencer 1991)

Survey Unit	Commercial timberland	Other[a]	Reserved[b]	Total forest land
Eastern Ozarks	4,110.0	31.2	159.1	4,300.3
Northwest Ozarks	2,169.6	116.6	27.2	2,313.4
Prairie	2,500.3	15.2	16.9	2,532.5
Riverborder	2,092.7	85.0	60.9	2,238.6
Southwest Ozarks	2,498.2	62.4	52.8	2,613.4
Total	13,370.8	310.5	316.9	13,998.2

[a] Forest land not capable of producing 20 cf/A/yr of industrial wood crops under natural conditions.

[b] Forest land withdrawn from timber utilization through statute, administrative regulation, designation, or exclusive use for Christmas tree production as indicated by annual shearing.

In 1988, the most recent year for which data is available, public lands provided 19.7% of the sawtimber harvested statewide. This amount ranged from 26.8% of the sawtimber harvested in the Southwest Ozarks Unit, 26.7% of the sawtimber in the Eastern Ozarks Unit, 18.3% of the sawtimber in the Riverborder Unit, 7.8% of the sawtimber in the Northwest Ozarks Unit, to only 1.3% of the sawtimber in the Prairie Unit (Table 3). If viewed from another standpoint, the Eastern Ozarks Unit provided 40% of the total sawtimber harvest in the state and the Prairie Unit only provided 15% of the total sawtimber harvest. In contrast, the Prairie Unit contains slightly over 44% of the total land area in the state and the Eastern Ozarks Unit contains only 13% of the total land area in Missouri.

THE EASTERN OZARKS UNIT

The Eastern Ozarks Unit is a 14-county area with the lowest total population of the five survey units. These counties (and their population rankings at the time of the survey) are: Bollinger (86), Butler (20), Carter (110), Crawford (50), Dent (66), Iron (82), Madison (84), Oregon (87), Reynolds (105), Ripley (70), St. Francois (15), Shannon (100), Washington (51), and Wayne (81) Counties. This area has the greatest number of loggers, sawmills, and other primary mills (Table 4). Of the five units in the state, this is far and away the largest wood-producing region. Of more than passing interest is the Nature Conservancy's very recent purchase of some 80,819 A of what was considered forest industry lands in Carter, Shannon and Wayne counties. This land will apparently be managed by the Missouri Department of Conservation. Initial indications are that some of these lands will be removed from commercial timber production.

Since the Eastern Region already has the largest amount of public ownership land (Table 1), we will concentrate our attention on this region. Of the 14 counties in the Eastern Ozarks, only two counties have less than 50% of their total land area classified as commercial timberland: St. Francois County, 49.3%; and Butler County, 29.3% (Table 5).

Table 3.—Sawtimber Removal on Commercial Timberland, 1988 (Thousands of board feet, International 1/4" Rule) (from Hahn and Spencer 1991, and Spencer et al 1992)

Survey Unit	Nat'l Forest	Misc. Federal	State	Other public	Forest industry	Private	Total
Eastern Ozarks	27,028	1,416	3,418	—	7,829	79,602	119,293
Northwest Ozarks	1,178	639	—	—	—	21,618	23,435
Prairie	—	—	598	—	—	44,926	45,524
Riverborder	2,769	—	1,763	5,965	438	46,383	57,318
Southwest Ozarks	10,570	—	2,809	—	274	36,259	49,912
Total	41,545	2,055	8,588	5,965	8,441	228,788	295,482

Table 4.—Estimated Population and Primary Forest Products Industries by Survey Units, 1989 (from Trokey et al 1991)

Survey Unit	Estimated population	Loggers	Pallet sawmills	Other mills	Primary[a]
Eastern Ozarks	217,780	335	182	30	26
Northwestern Ozarks	229,790	51	33	6	13
Prairie	1,913,750	145	66	34	10
Riverborder	2,311,840	129	47	12	5
Southwestern Ozarks	244,370	131	80	12	23
Total	4,917,530	791	408	94	77

[a] This includes veneer mills, cooperage mills, charcoal producers, pole/post/piling mills, and miscellaneous product mills.

Table 5.—Eastern Ozarks Region — Population and public lands (in thousands of acres)

County	Rank	Population	Land area	Commercial timberlands All owners	MTNF	Misc. public
Bollinger	86	10,301	397.2	215.5	1.6	—
Butler	20	37,963	446.7	130.7	47.4	3.1
Carter	110	5,428	325.8	266.3	90.2	20.6
Crawford	50	18,300	475.9	321.9	48.3	24.4
Dent	66	14,517	483.1	302.4	67.3	28.3
Iron	82	11,084	353.3	275.9	81.2	3.3
Madison	84	10,725	318.2	239.6	38.8	3.4
Oregon	87	10,328	506.9	292.6	71.0	—
Reynolds	105	7,230	517.4	425.5	85.5	53.8
Ripley	70	12,458	404.2	269.0	94.2	4.7
St. Francois	15	42,600	288.7	142.3	0.9	—
Shannon	100	7,885	533.2	466.5	83.4	61.6
Washington	51	17,893	487.8	375.2	78.1	13.4
Wayne	81	11,277	487.9	386.5	85.9	21.6
			4,110.0	873.8	238.2	

Table 6.—Estimated Direct Economic Impact of Forest Products Industry in the Eastern Ozarks, 1989

Sector	Wood	Other materials	Labor	Business expenses	Employees
	(millions of dollars)				
Logging	53.3	0	17.9	24.1	1,482
Sawmills and drying	71.0	0	25.8	29.0	1,918
Pallets	17.4	10.4	11.4	8.2	955
Other primary	19.6	1.6	2.4	2.5	159
Secondary mfgtrs	13.8	9.9	16.5	5.4	1,100
Total	174.9	21.9	74.1	69.3	5,614

This region contains some 42% of the firms engaged in logging, 45% of the sawmills and drykilns, 32% of the pallet plants, 34% of the other primary producers, but only 10% of the secondary manufacturers. The monies that are spent by these industry groups are shown in Table 6. The sum total of these expenses for wood and other raw materials, labor, and business expenses is some $340 million. While we have separated these groups into discrete sectors, they are very much interconnected and interdependent.

While some of the purchases by these various groups are made outside the region, many are made locally. An estimated $25 million annually in additional business in other non-forest sectors results from such activity.

Payments for Schools and Roads

If the timber available from public lands in the region, some 26.7% of the 1988 statewide harvest, were withdrawn from the market, the results potentially would be devastating to individuals and to the small, rural communities. Among other losses would be the payments from the federal government to local governments based on the harvest of timber from the Mark Twain National Forest lands in their jurisdictions. This payment amounts to 25% of all monies received (based on all income) and is to be expended as the state legislature may provide for the benefit of public schools and public roads of the counties in which the National Forest is situated in proportion to the land contained in each county. In the case of timber sales, the payment is based on stumpage prices. As an example, in 1988, some 41,545 Mbf of sawtimber were harvested from the Mark Twain National Forest in Missouri. If we assume an average statewide stumpage price of $95/Mbf, this amounts to some $985,980 that would have been divided proportionately among the 29 counties. With the recent concerns over reductions in primary and secondary school funding in Missouri, withdrawal of these monies could have significant impacts on the financial health and/or continued existence of some school districts.

A prime example would be Carter County which ranks 110th of 114 counties in terms of population in the state (5,428 residents) and contains 90,200 acres of National Forest (and another 20,600 acres of state-owned land) out of a total land area of ca. 266,400 acres. Slightly over 6.8% of the Mark Twain National Forest lands in Missouri are found in Carter County. Assuming a proportionate sharing of revenues, in 1988 Carter County schools and roads would have received about $67,340 from timber sales on the Mark Twain National Forest. In the case of schools, this would be the equivalent of 3 or 4 teachers. As a matter of historical record, the average annual harvest from the Mark Twain National Forest for the period 1977-1989 is 57,354 Mbf (Kingsley and Law 1991). This equates to a decrease of some 28% in sawtimber harvest from the annual harvest with a corresponding decrease in real dollar income at the county level. In the case of Carter County, this would amount to an annual loss of $25,690. Much of this probably comes from the increase in what is termed "Reserved Forest Land" (Table 2). This has increased statewide from 256,100 A in 1972 to the 1989 level of 316,900 A. On the National Forest, this is largely accounted for by increases in designated wilderness areas.[2]

Possible Consequences of Reduction of Public Land Base

For argument's sake, let us consider what the effect would be of removing the Mark Twain National Forest lands completely from timber harvest. As a point of information, remember that most forecasts for wood consumption in the United States for the foreseeable future project an increase in demand. These forecasts also predict at best no change in available commercial timberland and most forecast a decrease in land available for timber harvest. The eastern hardwoods region, which includes Missouri, is projected to supply a greater share of wood and wood products than they do now.

---

[2] The Mark Twain National Forest Annual Report for FY 1991 indicates that total 25% payments were $1,999,913.90 and FY 90 PILT payments were $630,070. For Carter County, these numbers were $124,453.27 and $37,574 repectively. Timber harvest in 1990 amounted to 50.506 MMbf.

The majority (83.3%) of the commercial timberland in Missouri is considered to be non-industrial private forest. Much of this land is in relatively small holdings (less than 500 A). Trokey and Kurtz (1982) suggested that approximately 60% of the land is currently being used for timber harvest. Further, that at best, only another 20% of the land might become available for timber harvest. This assumes two things: (1) landowner education programs and technology transfer carried out by state agencies and/or forest industry, and (2) stumpage price increases. In either event, additional professional personnel would be required to conduct landowner education and assistance programs. These programs would cover not only the desirability of timber harvest, but environmentally and silviculturally appropriate ways to do the harvest so that damage to residual stands is minimized if not eliminated. Such programs are in place in other states at this time.

In the Eastern Ozarks Unit, the overall average harvest per acre in 1988 was 29 bf/A. This ranges from an average of 17 bf/A on state-owned lands to 42 bf/A on forest industry-owned lands. On the Mark Twain National Forest, the average was 31 bf/A. To continue the same level of production in the Eastern Ozarks Unit would require that production from private lands increase from the current 28 bf/A to an average of 39 bf/A. Since our earlier suggestion that only 60% of the NIPF land was being used, this suggests that actual harvests are in the range of 47 bf/A and would increase to 63 bf/A. If the education and motivation process discussed earlier were effective, the required harvest would still be 47 bf/A from 80% of NIPF lands. The most recent data indicates that statewide sawtimber growth averages 75 bf/A while sawtimber removals are averaging 31 bf/A so the capacity exists to provide the additional sawtimber without exceeding the resource.

While there are some 197,100 A of state-owned land in the Eastern Ozarks, the needed timber supply could not be realistically filled by increasing sawtimber removals. This would require state lands to produce 154 bf/A, a figure that exceeds annual growth and would lead to depletion of the resource. The latter is an unacceptable consequence.

In addition to the change in production from public to the private sector, there would also be the loss of the monies resulting from timber harvest on the National Forest lands. While there might be increased receational activity on these lands, it is doubtful whether the loss in designated school or road income would be overcome. In FY 1991, recreation provided less than 1% of the total income on the Mark Twain National Forest.

Under Subtitle G of the 1990 Farm Bill — Title XXIII (Rural Development), a chapter entitled "National Forest-Dependent Rural Communities Economic Diversification Act of 1990", deals with the economic ramifications of removing the National Forest lands from commercial timber (or mineral) production. One of the purposes of Subtitle G is:

> "to provide assistance to rural communities that are located in or near national forests and that are economically dependent upon forest resources or are likely to be economically disadvantaged by Federal or private sector land management practices;"

This act in essence, directs the Forest Service to provide assistance to rural communities (less than 10,000 population) or counties (less than 22,500 population) "in which at least 15% of the total primary and secondary labor and proprietor income is derived from forestry, wood products, and forest-related industries such as recreation and tourism, that is located within the boundary, or within 100 miles of the boundary, of a national forest."

A quick look at the Mark Twain National Forest in Missouri indicates that most of the Eastern Ozarks region fits quite nicely in the geographic guidelines, and (we suspect) the economic guidelines as well. The two counties which exceed the population guidelines (Butler and St. Francois) also have the lowest percentage of commercial timberland in the region (Table 5). Butler County lies at the junction between the forested Ozarks and the largely agricultural Bootheel area of Missouri. St. Francois County is just south of the Riverborder and metropolitan St. Louis area and was the birthplace of lead mining in Missouri.

The other major source of income for the region is lead mining. The majority of Missouri's active lead mines lie within the Eastern Ozarks region and contribute between 1/2 and 2/3 of the 25% payments from the Mark Twain National Forest. These percentages vary directly with the production of the lead mines. There has been spirited and often acrimonious debate about whether additional exploration and mining should be permitted on the public lands in Missouri.

Industry Change Consequences

There always exists the possibility that the industry itself will undergo realignment as a result of either market pressures or government regulation. At present, Missouri is still a leading producer of wood charcoal. Recent estimates indicate that the charcoal industry contributes some $36.6 million to the Eastern Ozarks economy and some $117 million to the statewide economy. Most, if not all, of the wood is converted to charcoal by pyrolysis in "Missouri charcoal kilns" before going to briquetting plants for grinding and forming. In the past, these kilns have come under scrutiny for the large amounts of smoke and particulate that are emitted during the firing process. Missouri's recently-passed 1992 Clean Air Act imposes a "tax" of some $25 per ton of pollutants released on all industries in the state. The legislation is expected to cost Missouri's charcoal industry some $1.2 million annually. Should these kilns be forced to close, there would be a significant impact on local economies. The raw material for these kilns is primarily slabwood from sawmills, although a small amount of lowgrade roundwood is still used.

On the other hand, positive impacts cannot be ruled out either. There is a large amount of sawtimber in the Eastern Ozarks that, while lowgrade for most of today's solid wood uses, could be used for feedstock for chip-based, fiber-based, or chemical-derived products. The first two groups includes products such as structural flakeboard, medium-density fiberboard and a variety of paper products while the last group includes methanol and ethanol. Placement of any of these type of plants in or near the Eastern Ozarks would have a positive benefit to the economics of the region. At the same time, the supporting infrastructure might need to be upgraded which would have an initial short-term thrust for selected areas of the economy.

Scenarios can be constructed for a wide variety of plant sizes and types located in areas where the transportation system is sufficient. For example, Poplar Bluff is a town of some 25,000 people located at the junction of US 60 and US 67 with a major rail line (Union Pacific) running through town. A hypothetical 112.5 million square feet (MMSF) capacity 1/2" structural flakeboard plant using a mixture of chips and roundwood would cost some $139.5 million dollars (USDA Forest Service 1978, data adjusted for 1990 prices). These monies include the cost of the building and equipment, raw materials, manufacturing, etc. Much of these monies would remain in the local area although obviously much of the manufacturing equipment would need to be purchased outside the region. This plant would require some 8 to 9 million cubic feet of raw material as a mixture of 60% roundwood and 40% chips per year. The plant would employ between 70 and 80 people in addition another 100 to 120 engaged in procuring and supplying the raw materials and supporting services to the mill.

While out of necessity, plants such as this are located nearer population centers and have good access to markets, they will have an impact on small, rural communities such as exist in much of the Eastern Ozarks. It is in these areas where the raw materials are growing and will continue to grow. For the hypothetical flakeboard mill, some 5 million cubic feet per year or 30 MMbf per year of roundwood (assuming a 60% roundwood mix) would need to be obtained. At a removal rate of 30 bf/A, this means some 1,000,000 acres per year would need to be harvested. Current removals are occurring from over 4.1 million acres. It is highly likely that some of the raw material would be imported from other areas such as Arkansas and Illinois so that the impact would be distributed across a wider region. The increased demand for roundwood would probably drive the price of stumpage up and more land might become available for harvest.

CONCLUSIONS

The forest products industry in Missouri contributes in excess of $2.5 billion per year to the economy and provides direct employment for some 41,800 people. Many of these people are employed in the primary production end—logging and sawmilling—of the industry and are from less populated areas of Missouri. These are more labor-intensive jobs that utilize the avaliable human capital in the region in a most efficient manner. About 19.7% of Missouri's annual sawtimber harvest comes from public lands, which are also located in rural areas. It would appear that alteration of current public land forest resource management strategies could have significant impacts on local economies in regions such as the Eastern Ozarks, an area that provides 40% of the state's sawtimber supply.

REFERENCES

Devino, G. and K. Braschler. 1991. The economic impact of the forest industry on Missouri's economy. Department of Agricultural Economics, University of Missouri-Columbia. Unpublished report for the Missouri Department of Conservation.

Hahn, J.T. and J.S. Spencer, Jr. 1991. Timber Resource of Missouri. USDA Forest Service Resource Bulletin NC-119. 123 p.

Kingsley, N.P. and J.R. Laws. 1991. Timber Resource of the Mark Twain National Forest. USDA Forest Service Resource Bulletin NC-129. 31 p.

Spencer, J.S., S. M. Roussopoulus, and R.A. Massengale. 1992. Missouri's Forest Resource, 1989: An Analysis. USDA Forest Service Resource Bulletin NC-139. 84 p.

Trokey, C.B. 1981. An Analysis of Timber Management Potentials for Private Nonindustrial Forest Landowners. M.S. Thesis. University of Missouri-Columbia. 122 p.

Trokey, C.B. and W.B. Kurtz. 1982. Increasing timber management through a better understanding of nonindustrial private forest owners' motivations and objectives. The Consultant. 27(3):57-59.

Trokey, C.B., B.E. Cutter, and W.B. Kurtz. 1991. Contributions of the Forest Industry to Missouri's Economy. School of Natural Resources, University of Missouri-Columbia. Unpublished report for the Missouri Department of Conservation.

USDA Forest Service. 1978. Structural Flakeboard from Forest Residues. USDA Forest Service General Technical Report WO-5. 241 p.

The Effect of Small Rodents on Northern Red Oak Acorns in North-central West Virginia

Linda S. Gribko and David M. Hix[1]

Abstract: The effects of small mammals on surface-sown northern red oak (Quercus rubra) acorns was assessed in highly productive Appalachian hardwood stands. Study plots were established in October 1990 on excellent (average site index of 89 feet for red oak) and good (average site index of 72 feet) sites. Each plot included: 1) a rodent-proof exclosure, 2) an exclosure accessible only to small rodents, and 3) a non-enclosed open quadrat. By comparing the survival of acorns on the rodent-accessible quadrats with that on the open quadrats, it was determined that small rodents have a highly significant effect on the acorn crop. Of the 360 acorns placed in the open, only 10 survived until June. Only seventeen of 360 survived on the partially enclosed quadrats. It was determined through snap-trapping that white-footed and deer mice (Peromyscus spp.) were primarily responsible for removal of the acorns from the partially enclosed quadrats. In addition, it was determined through the use of regression analysis that small rodent damage to the acorn crop was greatest in stands that included small snags and large non-red oaks in the upper canopy.

INTRODUCTION

Throughout the Appalachian hardwood region, the regeneration of valuable species such as northern red oak (*Quercus rubra*) is often unsuccessful. This is particularly true on the more productive sites where yellow-poplar (*Liriodendron tulipifera*) and black cherry (*Prunus serotina*) often dominate after harvest cuts (Sander and Clark 1971). These faster-growing, more shade intolerant species tend to outcompete slow-growing oak seedlings and, in the absence of advance oak regeneration, may all but preclude oak from newly established stands.

Many factors are involved in the establishment of advance oak regeneration. Among these, the destruction of acorn crops by insects and animals has historically been of interest to both forest and wildlife managers. Much of the early work of investigators such as Korstian (1927), Wood (1938), Downs and McQuilken (1944), Gysel (1957), and Tryon and Carvell (1962) indicates that animals and insects often cause significant or total loss of acorn crops. More recently, several researchers have found that small rodents, rather than larger game species such as deer, squirrels, and turkey, may cause the greatest amount of animal damage to acorn crops (Shaw 1968, Marquis et al. 1976, Delong and Yahner 1991). The destruction of the entire crop by animals and insects can be expected in years of low to moderate acorn production. Therefore, it has been suggested that most oak seedlings are established when acorns are overlooked in years of bumper crops (Olson and Boyce 1971).

Healy (1988) notes a relative lack of evidence to support the contention that acorn predation by animals is a serious factor in the regeneration of Appalachian hardwoods. Additionally, little information is available to assist forest managers in identifying stands in which animals may be a serious impediment to the establishment of oak. This paper describes the results of the first year of a 2-year study conducted in northern West Virginia to determine the site-specific effects of small mammals on northern red oak acorn crops. In addition, it suggests silvicultural practices that may lessen the impacts of small mammals on highly productive Appalachian hardwood sites.

---

[1] Graduate Research Assistant, West Virginia University, Morgantown, WV; and Assistant Professor, Ohio State University, Columbus, OH.

METHODS

This study was conducted on the West Virginia University Forest located in north-central West Virginia along the westernmost range of the Allegheny Mountains. Two study sites were selected. The first site was located in the Lick Run watershed of the Forest where cove hardwood stands were selected on a northeast-facing slope. This study area was characterized by very high site indices for northern red oak (81 to 97 ft.), an abundance of mature yellow-poplar and northern red oak, and a moderate ground cover of herbaceous and woody vegetation. The second site was located in the Glade Run watershed of the Forest. The stands selected in this area were located on a drier northwest-facing slope and were characterized by lower site indices for northern red oak (68 to 73 ft.), an absence of yellow-poplar, a significant component of mature black cherry, and sparse ground cover. These study areas will henceforth be referred to as the Lick Run and Glade Run sites.

Square plots of 0.5 acre were established on each site. Due to constraints imposed by a concurrent study, six plots were located on the Lick Run site and four were located on the Glade Run site. On each plot, four mature (> 12 inches dbh) dominant or co-dominant northern red oaks were selected. A cluster of three 1-foot square quadrats was randomly located within the area under the crown of each of these 40 trees. One of the quadrats in each cluster was fully enclosed with 0.5-inch mesh hardware cloth to exclude all potential mammalian and avian predators. These exclosures were constructed with mesh bottoms to prevent predators from entering from below. The second quadrat in each cluster was enclosed on the top and sides, but not below, with 0.5-inch mesh hardware cloth. In addition, a 2-inch by 2-inch square opening was cut at ground level on each side of the exclosure. These quadrats were accessible to small rodents such as mice and chipmunks but were not accessible to other predators including squirrels. The last quadrat in each cluster was marked with stakes and left open to allow access to all potential acorn predators. The tops of all of the exclosures were hinged so that they could be opened for observation as the study progressed.

Northern red oak acorns were collected off the study area in September of 1990. The acorns were tested for viability using the float method (Schopmeyer 1974). Apparently sound, undamaged acorns were placed on each quadrat in a square grid pattern. Nine acorns per quadrat was determined to be a reasonable approximation of that naturally occurring on a 1-foot square area as suggested by Gysel (1956). The acorns were pressed slightly into the humus to prevent them from rolling but were not buried.

The quadrats were checked biweekly to monthly from late fall until germination in the spring. Each acorn was recorded as damaged by insects, damaged by animals, removed, or germinated. In addition, litter depth was monitored and adjusted within the exclosures to approximate that on the open quadrat.

A complete tally by 1-inch class of all trees 2 inches dbh and above was taken on each 0.5-acre plot. In addition, the distance was measured from the center of each cluster to the nearest: seedling (< 3 feet tall), small shrub/sapling (3 to 10 feet tall), large shrub/sapling (> 10 feet tall but less than 4 inches dbh), small pole (4 to 8 inches dbh), large pole (8 to 12 inches dbh), mature tree of any species (> 12 inches dbh), mature soft-mast producing tree, mature hard-mast producing tree, small snag (< 10 inches dbh), large snag (at least 10 inches dbh), open water or seep, fallen or cut log, tops or branches, and rocks. Most of the study area was at one time mined for iron ore resulting in pit and mound soil disturbance. Since these soil mounds were used extensively by mice for nesting, the distance to the nearest mound was recorded. Ocular estimates of percent woody debris and percent rock cover within a 100-foot diameter circle originating at the cluster center were also made.

Snap-trapping of small mammals was conducted on five consecutive nights in early December 1990 to determine relative densities and species composition of animals on the plots. Four parallel trap lines, each 150 feet in length, were established on each plot. Each trap line consisted of six trap stations placed at 25-foot intervals. Each trap station included three snap-traps placed approximately equidistant from the center of a 3-foot diameter circle. Eastern chipmunk and southern flying squirrel populations were sampled by including a rat trap in every third trap station.

RESULTS

Acorn Survival

Very few of the acorns that were accessible to small mammals survived to germinate in the spring. Of the 360 placed on the open quadrats, only 10 remained in early June. Seventeen of the 360 acorns on the partially enclosed quadrats survived.

Chi-square analysis was performed on the fate of the acorns on the open and partially enclosed quadrats. Overall, there was no significant difference between acorn removal on open and partially enclosed quadrats (Chi-square = 1.886, $p > 0.05$). As can be seen in Figure 1, where total number of surviving acorns is plotted against number of days, acorn removal rate is nearly identical on the two types of quadrats.

Chi-square analyses were performed by plot by combining the results from the four clusters of quadrats on each plot. For only one plot, located in the Glade Run watershed, were the results significant at the 0.05 level. On this plot, eight of the 36 acorns on the partially enclosed quadrats survived, whereas only 1 survived on the open quadrats (Chi-square = 6.22, $p < 0.05$).

With such complete removal of acorns from the quadrats, it is difficult to identify stand variables that may be influencing survival. Therefore, a new dependent variable, acorn survival days, was used in the multiple regression analysis of stand variables. Acorn survival days, the mean number of days the acorns survived on each quadrat, is a good indication of the intensity of acorn predation on the plots.

The basal area of non-red oak dominant and co-dominants per acre and the minimum distance to a snag less than 10 inches dbh were found to be significantly correlated at the 0.01 level with acorn survival days. The non-red oaks included primarily white oak and chestnut oak, although one plot contained scarlet oak and another included a small number of black oaks. After natural log transformation of acorn survival days and the independent variables, linear regression was used to develop the following model:

$$\ln(ASD) = 3.301 - 0.603*\ln(BPA) + 0.555*\ln(SNAGD)$$

where ASD = mean acorn survival days, BPA = basal area of non-red oak dominant and co-dominant trees per acre, SNAGD = minimum distance to a snag less than 10 inches dbh, and $r^2 = 0.74$. The relationship between acorn survival days and each of the independent variables is shown in Figure 2.

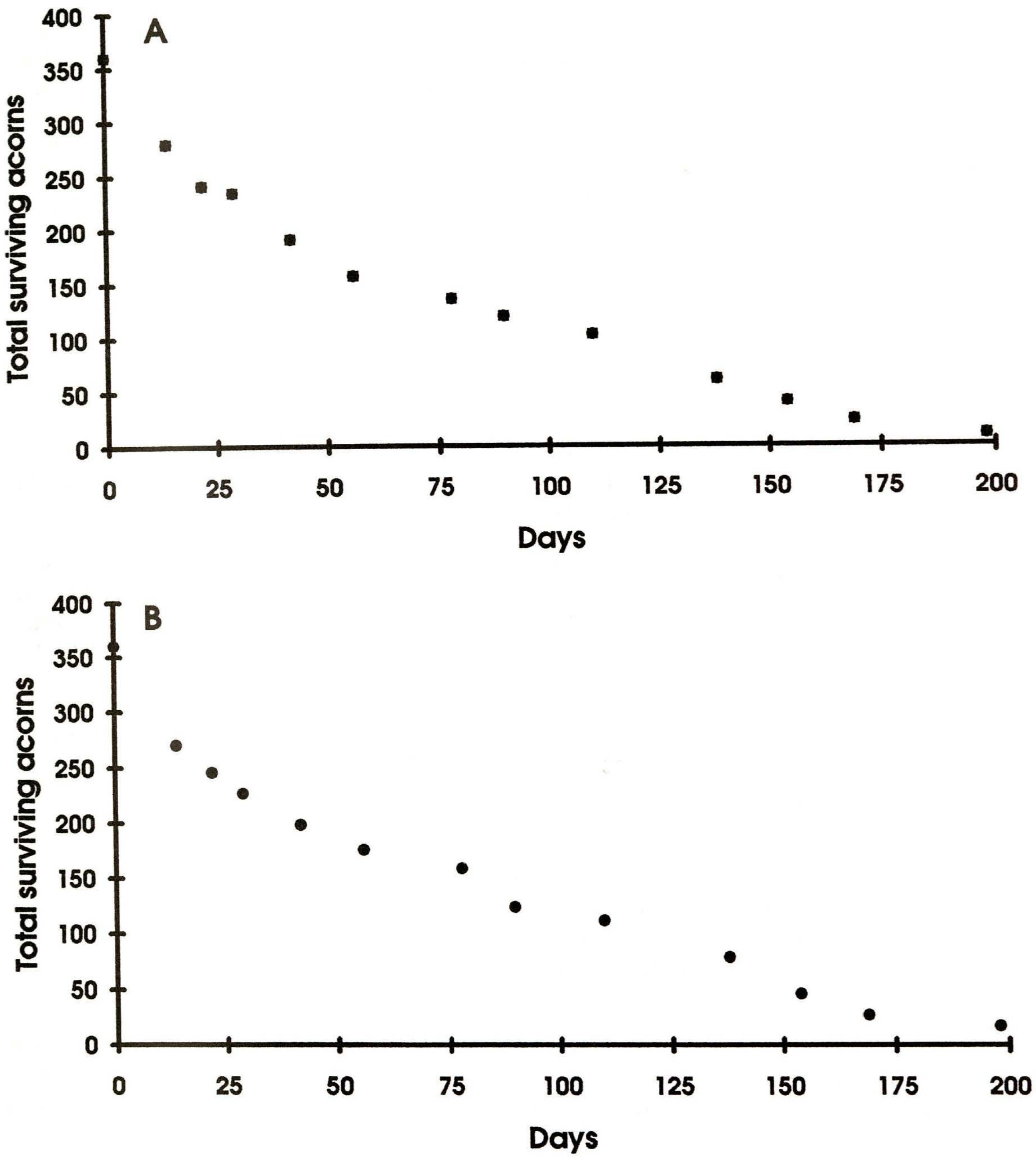


Figure 1.—Captures of small rodents in the Lick Run and Glade Run watersheds.

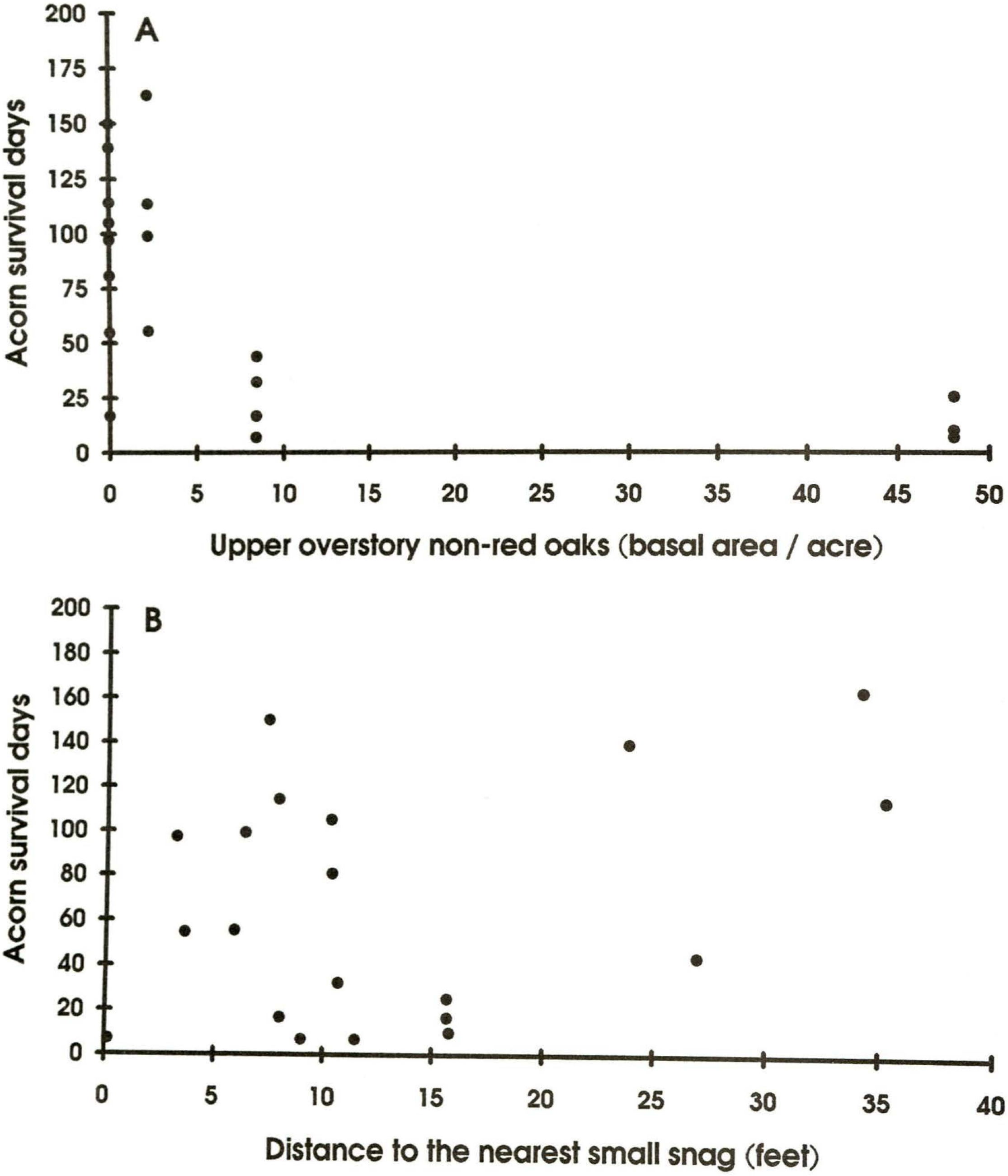


Figure 2.—Total surviving acorns over time on: A) open quadrats and, B) partially enclosed quadrats.

Small Mammal Trapping

The results of the small mammal trapping are presented in Table 1. White-footed and deer mice (*Peromyscus* spp.) and red-backed voles (*Clethrionomys gapperi*) were present throughout the study area and were well-represented in the sample. Southern flying squirrels (*Glaucomys volans*) were trapped on only a single plot in the Lick Run watershed. A few masked shrews (*Sorex cinereus*) were also trapped on the Lick Run plots. In addition, eastern chipmunks (*Tamias striatus*) were seen on the plots earlier in the fall but did not appear in the sample. This may have been due to the late date of the trapping (early December) and limited foraging activity of chipmunks during the 5-day trapping period. Short-tailed shrews (*Blarina brevicauda*) were also absent from the sample even though they were successfully trapped on the study area the following year.

Table 1.—Captures of small rodents in the Lick Run and Glade Run watersheds

	Captures/100 trap nights	
	Lick Run	**Glade Run**
Mice and voles:		
Peromyscus spp.	15.05	5.79
Clethrionomys gapperi	11.57	10.42
Squirrels and chipmunks:		
Glaucomys volans	10.42	0.00
Tamias striatis	0.00	0.00
Shrews:		
Sorex cinerus	2.31	0.00
Blarina brevicauda	0.00	0.00

Pearson correlations indicate that, at the 0.05 level, *Peromyscus*, southern flying squirrel, and masked shrew captures per 100 trap nights were all negatively correlated with acorn survival days ($r = -0.69$ for *Peromyscus*, $r = -0.53$ for southern flying squirrel, and $r = -0.77$ for masked shrews). The relationship between acorn survival days and *Peromyscus* captures is shown in Figure 3. Red-backed vole captures per 100 trap nights were not found to be significantly correlated with acorn survival days ($r = 0.17$). In addition, capture of masked shrews per 100 trap nights was found to be highly positively correlated with capture of *Peromyscus* and southern flying squirrel ($r = 0.91$ for *Peromyscus* and $r = 0.61$ for southern flying squirrel).

Pearson correlation between captures of *Peromyscus* and basal area of non-red oaks in the upper canopy indicates that captures increase as basal area increases ($r = 0.60$, $p = 0.01$). However, captures of *Peromyscus* was not found to be significantly correlated with minimum distance to a snag ($r = -0.14$, $p > 0.05$).

Due to the limited capture of southern flying squirrels, numbers of this species could not be related to the two stand variables. However, the plot on which flying squirrels were found included many large residual white oaks.

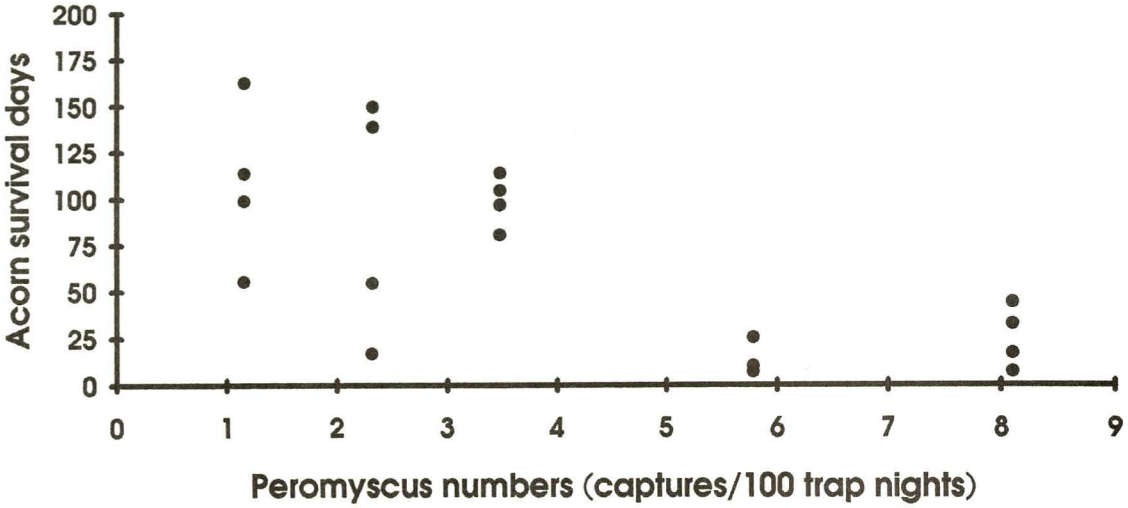


Figure 3.—Acorn survival days versus Peromyscus captures per 100 trap nights.

DISCUSSION

The results of the chi-square analysis on total acorn removal indicate that small mammals have a serious impact on red oak acorn survival in this study area. Acorns were removed quickly and almost completely from the partially enclosed quadrats. In addition, acorns were removed from the open quadrats at approximately the same rate, indicating that small rodents, and not the larger game species, were primarily responsible for acorn predation on open ground.

It is presumed that most of the removed acorns are consumed, destroyed, or cached in multiple-nut larders where they have very little chance of germinating successfully. Smith (1962) found in laboratory feeding trials that even though northern red oak acorns are not highly preferred by *Peromyscus*, they will be consumed in combination with other foods. It was also noted in these trials that *Peromyscus* will often destroy red oak acorns by gnawing or peeling the shell, rendering them non-viable or predisposing them to invasion by insects and pathogens. Even when red oak acorns do survive initial contact with small rodents, they are often cached in trees and under rocks and woody debris where germination is not probable (Sork, 1984).

Of the two small mammal species that were well-represented in the trapping sample, only *Peromyscus* can be considered a major consumer of acorns. The diet of the red-backed vole cannot be expected to regularly include acorns (Martin et al., 1951). Therefore, on this study area it can be assumed that *Peromyscus* were primarily responsible for the removal of acorns from the partially enclosed plots. The negative correlation between captures of *Peromyscus* and acorn survival days further implicates this species.

The results of the multiple regression on acorn survival days indicate that mouse damage to the acorn crop can be expected to be higher in stands that include small snags and large non-red oaks in the upper canopy. Small snags are often used by mice as food caching sites and also for hiding and nesting cover. The lack of a correlation between *Peromyscus* numbers and minimum distance to a snag indicates that small rodents may not necessarily be more numerous in areas where snags are present. However, they may be more active. It is probable that acorns are collected initially from areas close to caching sites such as snags. Later in the season as acorns become more scarce, small rodents could be expected to forage further away from the caching site and to be more willing to transport acorns over longer distances. This could explain the finding that acorns survived longer with increasing distance from a snag.

The plots that suffered the most intense acorn predation included large residual white oaks in the upper canopy. These plots, which contained from 8 to 48 square feet of basal area of white oak in very few large diameter trees, were located in the Lick Run watershed and were characterized by very high site indices for northern red oak. It was on these plots that *Peromyscus* captures were the highest. In contrast, the plots on which acorns survived the longest were located in the Glade Run watershed. These plots contained neither white oaks nor other non-red oaks in the upper canopy. They were characterized by lower site indices for northern red oak, and the lowest relative densities of *Peromyscus*.

The presence of dominant and co-dominant white and other oaks on the Lick Run plots may increase the suitability of these sites for *Peromyscus* by providing a more palatable and nutritious food supply than that provided by northern red oak acorns alone. Smith (1962) found that when given a choice among white, chestnut, and northern red oak acorns, *Peromyscus* will virtually reject the red oak while showing very high preference for white oak and moderate preference for chestnut oak. However, it may be reasonable to expect that mice will utilize northern red oak acorns as the supply of white oak acorns in the area is depleted.

CONCLUSIONS

The lack of successful northern red oak regeneration on good sites in the Appalachian hardwood region continues to be of concern to forest managers. The results of this study indicate that white-footed and deer mice are major consumers of acorns on very productive sites. Unlike squirrels, which are generally thought to aid regeneration through the dispersal and burial of acorns, mice can usually be considered detrimental. Their activity may severely impact oak regeneration through almost complete destruction of acorn crops in some years especially in stands with a very high site index and a mixture of oak species. Alteration of small rodent habitat through the removal of low-quality white and other non-red oaks from the overstory and the elimination of snags from the stand may reduce mouse numbers and aid in the regeneration of northern red oak on some highly productive sites.

LITERATURE CITED

DeLong, C.A., and Yahner, R.H. 1991. Impact of small mammals on regeneration of northern red oak. p. 581 in: McCormick, L.H., and Gottschalk, K.W., eds., Proc: Eigth Central Hardwoods Conference. March 4-6, 1991. University Park, PA. USDA For. Serv. Gen. Tech. Rep. NE-148. 605 pp.

Downs, A.A., and McQuilken, W.E. 1944. Seed production of Southern Appalachian oaks. J. For. 42:913-920.

Gysel, L.W. 1956. Measurement of acorn crops. For. Sci. 2:305-313.

Gysel, L.W. 1957. Acorn production on good, medium, and poor sites in southern Michigan. J. For. 55:570-574.

Healy, W.M. 1988. Effects of seed-eating birds and mammals on Appalachian hardwood regeneration. pp. 104-111 in: Smith, H.C., Perkey, A.W., and Kidd, W.E., eds. Proc.: Guidelines for regenerating Appalachian hardwood stands, May 24-26, 1988, W. V. Univ., Morgantown, WV. Soc. Amer. For. Publ. 88-03. 293 pp.

Korstian, C.F. 1927. Factors controlling germination and early survival in oaks. Yale University: School of Forestry Bulletin No. 19. 115 pp.

Martin, A.C., Zim, H.S., and Nelson, A.L. 1951. American wildlife and plants. McGraw-Hill Book Co., New York. 500 pp.

Marquis, D.A., Eckert, P.L., and Roach, B.A. 1976. Acorn weevils, rodents, and deer all contribute to oak regeneration difficulties in Pennsylvania. USDA For. Serv. Res. Pap. NE-356. 5 pp.

Olson, D.F., Jr., and Boyce, S.G. 1971. Factors affecting acorn production and germination and early growth of seedlings and seedling sprouts. pp. 44-48 in: White, D.E., and Roach, B.A., co-chairs., Proc: Oak symposium, August 16-20, 1971, Morgantown, WV. USDA For. Serv. N. E. For. Exp. Stat. 161 pp.

Sander, I.L., and Clark, F.B. 1971. Reproduction of upland hardwoods in the central states. USDA Agric. Handb. 405. 22 pp.

Schopmeyer, C.S., tech. coord. 1974. Seeds of woody plants in the United States. USDA For. Serv. Agric. Handb. 450. 883 pp.

Shaw, M.W. 1968. Factors affecting the natural regeneration of sessile oak (Quercus petraea) in North Wales. II. Acorn losses and germination under field conditions. J. Ecol. 56:647-660.

Smith, R.L. 1962. Acorn consumption by white-footed mice. W. V. Univ. Agric. Exp. Stat. Bull. 482T. 15 pp.

Sork, V.L. 1984. Examination of seed dispersal and survival in red oak, Quercus rubra (Fagaceae), using metal-tagged acorns. Ecology. 65(3):1020-1022.

Tryon, E.H., and Carvell, K.L. 1962a. Acorn production and damage. W. V. Univ. Agric. Exp. Sta. Bull. 466T.

Wood, O.M. 1938. Seedling reproduction of oak in southern New Jersey. Ecology. 19(2): 276-293.

Developing Regeneration in Woodlots at Gettysburg National Military Park[1]

Todd W. Bowersox, Gerald L. Storm, and Walter M. Tzilkowski

Abstract: Woodlots are significant features of the historic scene at Gettysburg National Military Park, Pennsylvania. Recent inventories of these historic woodlots indicated a general lack of seedling recruitment in the uneven-aged stands with a mature mixed oak overstory and a midstory of ash-cherry-dogwood-hickory. Seedling-sized stems of shrub and tree species were abundant, averaging over 40,000 per hectare. The tree species were dominated by ash and cherry, and many seedlings were browsed by white-tailed deer. April density of white-tailed deer increased from 0.25 white-tailed deer per hectare in 1987 to 0.40 white-tailed deer per hectare in 1992. A management strategy is needed to maintain the structure and species composition of the historic woodlots. We present an approach to develop methods for restoring and maintaining the historic woodlot scene.

INTRODUCTION

Gettysburg National Military Park was established to commemorate the July 1-3, 1863 Civil War battle. The Park presently covers about 1560 hectares with 643 hectares occupied by woodlots. Before 1863, woodlots ranging in size of 2 to 24 hectares were important cultural resources for the associated farms and communities. These woodlots provided shelter for livestock, fuelwood and a source of materials for buildings, fences, furniture and tools. Cavanaugh (1990) searched historic documents and Park photographs from the early 1900's. This research suggested that white oak (*Quercus alba* L.) was a dominate overstory species in these woodlots. On July 1, 1863 these woodlots were important landscape features for the Confederate and Union troops. Some woodlots were actual grounds of conflict whereas others were used as staging areas, screens for military movements or shelter for troops and supplies. To restore and maintain the landscape as it was in 1863, Natural Resource staff at the Park have organized the historic woodlots into two categories. The categories are (A) those associated with significant battle action and (B) those significant to battle movements and positions (Gettysburg National Park 1992).

Category A woodlots are to be restored and managed to reflect their historic appearance as part of an active battlefield. Height of overstory, density of overstory, mix of deciduous and coniferous species, and native species are important factors in preserving these historic scenes. Culp's Hill, Herbst Woods and Rose Woods are examples of Category A woodlots. These woodlots will require substantial vegetation manipulation to restore and intensive cultural practices to maintain the historic scene. Generally, the understory will be kept fairly open as it was at the time of the battle.

Category B woodlots served primarily as screens for army movements and positions, and are best interpreted and preserved as topographic features. Height of the overstory, mix of deciduous and coniferous species, and native species are important features in perpetuating these woodlots. Maintaining the understory conditions like at the time of the battle is of lesser importance in

---

[1] This research was supported by U.S. Department of Interior, National Park Service Mid-Atlantic Region under Cooperative Agreement 400-9-8004.

[2] School of Forest Resources, The Pennsylvania State University, University Park, PA 16802; Pennsylvania Cooperative Fish and Wildlife Research Unit, University Park, PA 16802; and School of Forest Resources, The Pensylvania State University, University Park, PA 16802.

category B woodlots. These woodlots are to be managed to sustain an uneven-aged structure. Cultural practices to establish artificial and natural regeneration, control of non-native species and selective removal of the overstory canopy may be used to maintain the historic features of these woodlots (Gettysburg National Park 1992).

Fairweather and Cavanaugh (1990) evaluated the species composition and structure of ten Park woodlots. In general, they found that each woodlot had numbers of trees per diameter class that were suggestive of uneven-aged structures. Oaks (*Quercus* spp.) dominated the trees >33 cm DBH whereas non-oaks, mainly black cherry (*Prunus serotina* Ehrh.), flowering dogwood (*Cornus florida* L.), hickories (*Carya* spp.), white ash (*Fraxinus americana* L.) and black cherry (*Prunus* spp.), dominated the trees between 2.5 and 22 cm DBH (Figure 1). Tzilkowski et al. (1993) reported white ash and black cherry were the most abundant seedling-sized stems in six Park woodlots.

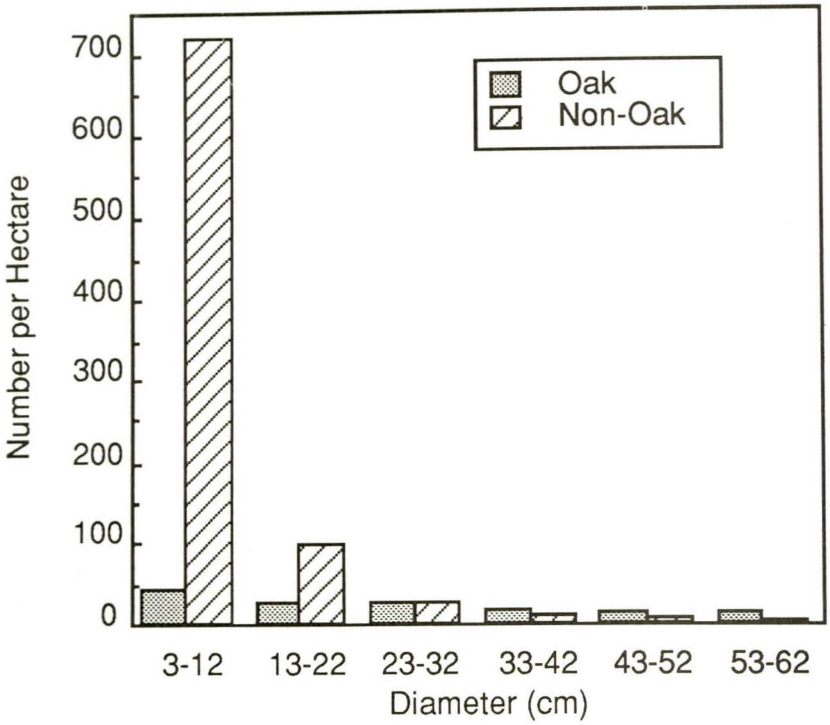


Figure 1.—Average number of trees per hectare for 10 woodlots inventoried 1989-1990 at Gettysburg National Military Park (Tzilkowski et al. 1992).

Deer browsing may account for the shift in species composition from oak dominated communities. Storm et al. (1992) have monitored white-tailed deer (*Odocoileus virginianus*) populations on 2833 ha adjacent to and within the Park since 1987. They used mark-resight and area conversion methods to estimate abundance. The mark-resight method was a bias-adjusted Lincoln-Peterson estimator (Otis et al. 1978, Seber 1982:60, White et al. 1982:19). The area conversion method was a census from complete counts on sample plots. Number of deer in each compartment counted in April varied considerable among the compartments within years but there was an overall increasing trend by compartment from 1987 to 1992 (Figure 2). Overall, April mark-resight estimates increased from 721±60 in 1987 to 1149±57 in 1992. Density increased from 0.25 white-tailed deer per hectare of total land (forested and non-forested) in 1987 to 0.40 per hectare in 1992. These values far exceed the Pennsylvania Game Commission management goal of 0.05 white-tailed deer per hectare for Adams County (Storm et al. 1989). There were no quantitative estimates of

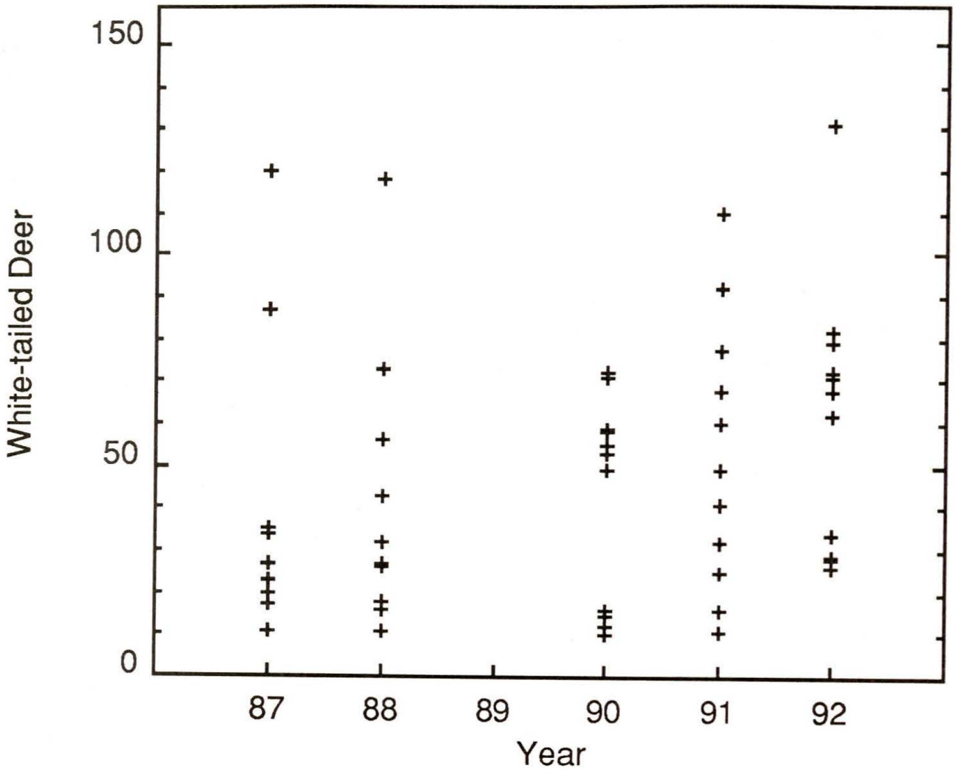


Figure 2.—April evening counts of white-tailed deer for the 11 compartments by year. Each point is an average of three inventories. There were no inventories in 1989.

white-tailed deer abundance prior to 1987 but Park personnel have considered the population to be high for at least 20 years. Storm et al. (1992) have also evaluated the availability and use of woody twigs by white-tailed deer in six Park woodlots. White ash, mazzard cherry (*Prunus avium* L.) and black cherry were most abundant twigs within 1.8 m of ground level with 6,868, 13,359 and 11,166 twigs per hectare, respectively. All oak species totaled 1,661 twigs per hectare. Frequency of browsing on the oak species ranged from none for pin oak (*Quercus palustris* Muenchh.) to 100% for black oak (*Q. velutina* Lam.). White ash and mazzard cherry and black cherry were also browsed with 44, 25 and 24%, respectively, of the twigs clipped by white-tailed deer.

Woodlot management practices may also account for the lack of oak seedlings, saplings and small diameter trees. Storm et al. (1992) evaluated the regeneration present in a pair of 10 x 10 m fenced and unfenced plots in five Park woodlots. Initially in 1987, there were 70,750 seedling-sized woody stems per hectare in the fenced plots and 73,250 stems per hectare in the unfenced plots (Figure 3). After the 1991 growing season the values dropped to 61,250 in the fenced areas and 42,250 in the unfenced areas. Loss of seedling-sized stems between 1987 and 1991 was substantial for white oak which dropped from 26,500 to 7,875 per hectare in the fenced areas and from 36,750 to 4,875 per hectare in the unfenced areas. There was considerable variation among the woodlots and the sample size was small. Nevertheless, these data suggest that seedling survival was being influenced by some factor in addition to white-tailed deer. Competition or interference from the overstory vegetation is one possible reason for seedling mortality. Openings in the canopy may be needed to establish replacements for stems lost to natural mortality, enhance the vigor of the remaining stems and maintain a healthy, sustainable stand structure.

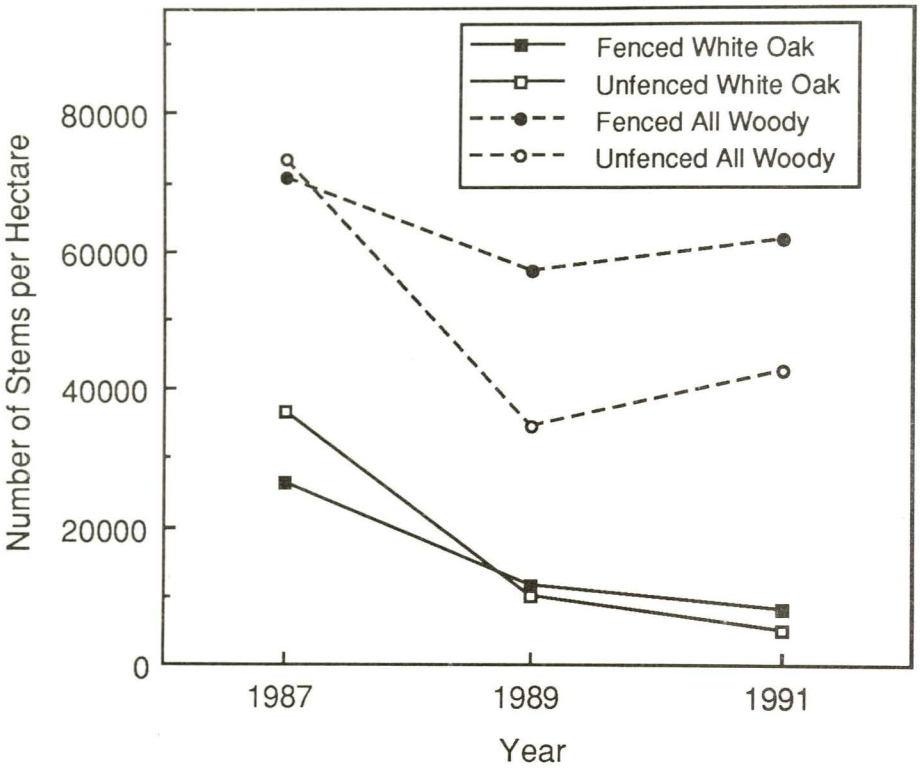


Figure 3.—Abundance of white oak and all woody seedling-sized stems in fenced and unfenced plots, by year of inventory.

Regeneration practices need to be organized so the richness of the flora and fauna in mixed oak communities will be maintained or strengthened. Even-aged regeneration methods are usually recommended for mixed oak stands because light is frequently the factor regulating seedling and sapling growth of most species common to the mixed oak stands. Selective removal of the overstory was a common practice in the woodlots surrounding Gettysburg in 1863. Fairweather and Cavanaugh (1990) suggested that selective cutting, with reduced browsing by white-tailed deer, could be used to increase the abundance of desirable species in the smaller size (younger age) classes. Single tree selection methods have been successful for regenerating shade tolerant species, such as sugar maple (*Acer saccharum* Marsh.). By varying the opening size from 0.08 to 0.81 hectares,, group selection has the potential to promote shade intolerant species.

There are several unknowns that seriously limit the application of selective cutting to any of the Category B mixed oak woodlots. These unknowns are:

1. What size openings in the canopy will be needed to establish and maintain a rich mixture of herbaceous and woody species?
2. Can the planting of seeds, seedlings or saplings be used to establish species that are difficult to regenerate naturally?
3. How can the white-tailed deer influence the nature and composition of the ground level vegetation?

Historical, cultural, biological, ecological and visual values need to be carefully integrated into the restoration and maintenance program for Category B woodlots. A research project has been developed to evaluate the effects of various sized openings in the overstory canopy, with and without white-tailed deer, on the ground level vegetation. This paper describes the development of canopy opening treatments to meet the unique management needs of the Park, and summarizes the pre-treatment understory conditions.

CANOPY TREATMENTS

Regeneration potential is being evaluated in three Category B mixed oak woodlots at the Park. These woodlots are Bushman Hill (22 ha), Herr Ridge (17 ha) and Powers Hill (21 ha). Bushman Hill had 860 trees per hectare, 25.70 m2 of basal area per hectare and was 108% stocked. Herr Ridge was 95% stocked with 717 trees per hectare and 21.35 m2 per hectare of basal area. Powers Hill had 810 trees per hectare, 16.50 m2 of basal area per hectare and was 73% stocked. The gently rolling topography of the Park is in the Piedmont physiographic region of south central Pennsylvania. Bushman Hill and Powers Ridge have many large diabase boulders on mostly well drained Neshaminy (Ultric Hapludalf; fine-loamy, mixed, mesic) and poorly drained Towhee (Typic Fragiaqualf; fine-loamy, mixed, mesic) soils. Herr Ridge has mostly poorly to moderately well drained Lehigh soils (Aquic Hapludalf; fine-loamy, mixed, mesic) and poorly drained Croton (Typic Fragiaqualf; fine-silty, mixed, mesic) soils. These soils were derived from shale and limestone with diabase intrusions. Site quality was about average and if occupied by even-aged stands the site index for oak would be ≥70. All woodlots were >130 years old with uncertain histories before 1895 when the Park was established by the US War Department. No silvicultural activity has occurred in the three woodlots since 1895.

Each study stand will receive three replications of three overstory treatments. These treatments are:

1. Closed. A circular area of 0.2 hectares that is at the closed or fully occupied canopy level. This level will provide information on the regeneration potential with no openings in the overstory canopy. In these areas, direct sunlight can reach the understory vegetation as sun flecks. Indirect sunlight reaching the forest floor will be about 50% of maximum. Root competition from the residual trees on the seedlings and saplings should be very high.

2. Small. A circular area of 0.2 hectares in which the overstory canopy will be reduced to 60% of fully occupied level. Reductions in the canopy will be from single trees that have died or could be cut. This treatment will be representative of the single tree selection method of regeneration. In these areas, direct sunlight through the small openings in the canopy will add to the direct sunlight from sun flecks. Indirect sunlight reaching the forest floor will be increased by openings in the canopy and it is estimated that the amount of indirect sunlight will be about 75% of maximum. Root competition from the residual trees on the seedlings and saplings should be about 60% of full stocking levels.

3. Large. Natural openings from multi-tree mortality or possible tree felling that would have 50% of the opening receiving at least 6 hours of direct sunlight and 100% of the indirect light potential. These circular areas of about 0.2 hectares would be representative of the group section method of regeneration in which the opening radius would be about equal to tree height. Root competition from the residual trees on the seedlings and saplings should be near zero in the center of the openings.

Each woodlot was inventoried to determine the number of trees by species and diameter. Sample points were located in each woodlot on a 60 x 60 m grid which had random starting points. There were at least 15 sample points in each woodlot. Number of living trees by species and diameter at 1.4 m above ground (DBH) were recorded on a circular 202 m^2 plot. Woodlot species and size data were reviewed with Park staff to establish a stand structure that has the biological potential of meeting the Park's vegetation management objectives. A "target" stand structure was developed for each woodlot. Normally, trees exceeding the goal or target number in each diameter class would be removed. However, trees >42 cm DBH were designated by the Park as having the potential of being present in 1863, and should be reserved for their historic value. As the size of the potential historic tree increases with time, there will be less need to comprise the target stand structure or restrict the placement of large canopy openings.

Small Canopy Opening Treatments

Fairweather and Cavanaugh (1990) suggested that the diameter distribution described by a q=2 (by 5 cm diameter classes) should be appropriate for many of the Category B woodlots. This relationship was used to develop a stand structure, which was defined by having:

a. A DBH of 75 cm as the maximum sized tree.
b. An after-treatment stocking level of 60% of full stocking.

Stocking levels were determined from the stocking charts described by Roach and Gingrich (1968). As described above, the Park did not want to remove trees which were >42 cm DBH. Therefore, criteria for tree removal were:

a. Trees <42 cm DBH.
b. By size, trees in excess of the goal level which were of:
   1. Poor health and not likely to be alive in 15 years.
   2. Species that were in abundance.
   3. Species not likely achieve diameters >42 cm DBH.

For some plots it was necessary to remove trees >42 cm DBH to reduce the overstory stocking to 60%.

A target structure, and typical before cut and after cut structure is given in Figure 4. In all small canopy treatment cases, it was necessary to remove more trees <42 cm then would be normally desired. This necessity was not viewed as a major problem, particularly in the <20 cm diameter classes. These diameter classes were dominated by shrub species of flowering dogwood, redbud (*Cercis occidentalis* L.) and spicebush (*Lindra benzoin* L.). In most stands, the shrub species in the <20 cm size classes accounted for 50% of all stems.

Large Canopy Opening Treatment

Size and location of the natural openings in the overstory of each woodlot were recorded. These openings were the result of death or windthrow to overstory trees. Three natural openings were selected in each woodlot. Selected openings were representative of the range of conditions in the woodlot and had no apparent physical limitations to the establishment of regeneration. None of the natural openings had the required 2000 m² or 0.2 hectares free of overstory competition. The next option considered was to select openings that could be enlarged to the needed 0.2 hectares by cutting trees that were ≤42 cm. The last option considered was to enlarge the opening by removing trees >42 cm DBH using the same criteria as in the small canopy opening treatment.

REGENERATION

Wire fences 1.2 m high are being used to exclude white-tailed deer. Estimates of the free-ranging white-tailed deer densities for the unfenced areas will be obtained from actual surveys (Storm et al. 1989, Storm and Tzilkowski 1992)

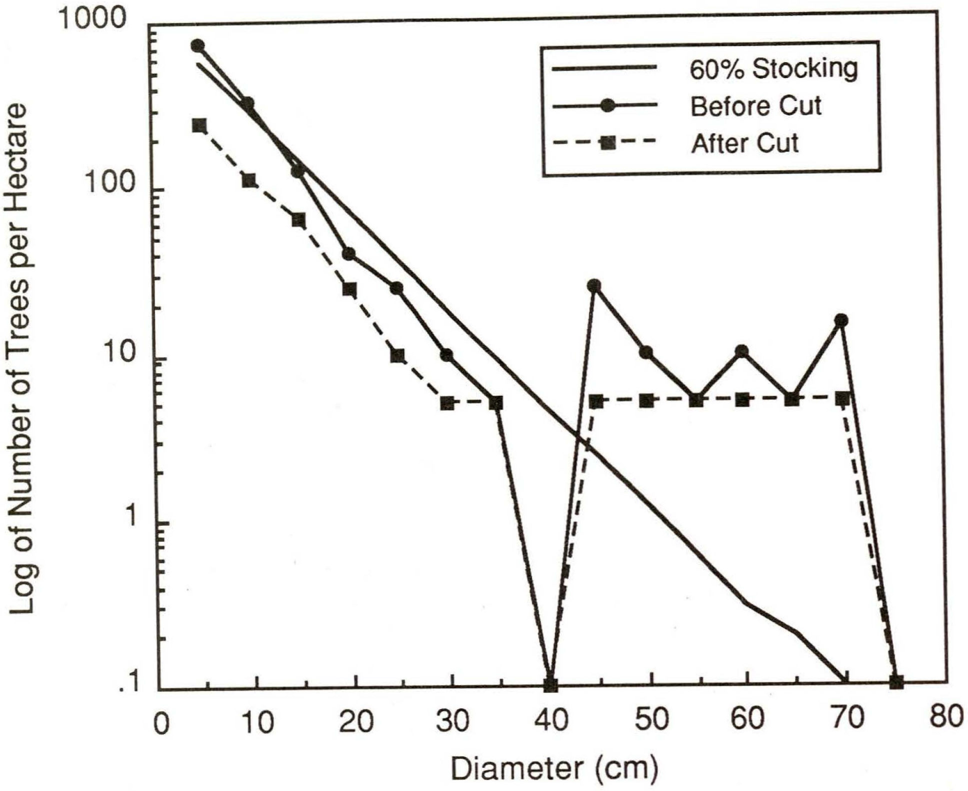


Figure 4.—An example small canopy opening treatment. Number of trees per hectare by 5 cm diameter (DBH) classes for a q of 2 and target stocking of 60%, number before cutting and number after cutting.

Abundance, composition and structure of understory vegetation were measured at the start of the study and will be measured the end of each growing season. We will measure and describe vegetation within each fenced and paired unfenced control plot based on the protocol developed by Storm and Ross (1992). Three pairs of fenced and unfenced 4.0 m2 plots have been established in each 0.20 hectares treatment unit to inventory the naturally established herbaceous and woody plant community. There will be 27 pairs of fenced and unfenced natural regeneration plots per canopy treatment for all study woodlots. For all study woodlots, there are a total of 81 paired natural regeneration plots. Herbaceous vegetation abundance and composition will be inventoried annually in June-July. Size and number of stems per woody species will be inventoried in May and October.

There were an average of 39,815 tree species stems per hectare and 55,865 shrub species stems per hectare for the three woodlots (Table 1). White ash dominated the tree species with an average of 19,800 stems per hectare. There was an average of 8,550 oak stems per hectare. Preliminary evaluations of the pre-treatment seedling-sized vegetation indicated no significant differences in the number of oaks, non-oak tree species, shrub species and total woody stems between the plots selected to be fenced and those to be unfenced. Overall, numbers of woody stems per hectare were significantly different for Bushman Hill (123,335), Herr Ridge (68,610) and Powers Hill (95,095) (Table 1). The average number of oak stems at Bushman Hill of 20,740 per hectare was significantly greater than the 2,408 and 2,871 stems per hectare at Herr Ridge and Powers Hill, respectively.

Table 1.—Average[1] number of stems per hectare for the three woodlots, by species group.

Species	Bushman Hill	Herr Ridge	Power Hill	Overall
	(—	—number of stems per hectare—		—)
Oak	20,740a	2,408b	2,871b	8,673
Other tree	44,445a	10,185b	38,795a	31,142
Shrub	58,150a	56,020a	53,425a	55,865
Total	123,335a	68,610c	95,095b	95,680

[1] Woodlot means within species group with the same letter were not significantly different at the 5% level.

[2] Oaks included black, chestnut, northern red, scarlet and white.

[3] Other trees included American elm, bitternut hickory, black cherry, black gum, black walnut, eastern red cedar, hackberry, mazzard cherry, mockernut hickory, Norway maple, pignut hickory, red maple, shagbark hickory, sugar maple, white ash and yellow-poplar.

[4] Shrubs included blackhaw, euonymous, flowering dogwood, grape spp., Japanese barberry, redbud, rose spp., rubus spp., sassafras, serviceberry, spicebush and witch-hazel.

A second set of paired fenced-unfenced plots will be used to evaluate the potential for successfully establishing and growing northern red oak (*Quercus rubra* L.) from direct seeding and planting of seedlings and saplings. Northern red oak was selected as a representative of species difficult to regenerate by natural processes. There will be two 12 m² fenced and unfenced plot pairs per replication of each treatment in each woodlot. There will be 18 paired artificial regeneration plots per canopy treatment for all study woodlots. Over all study woodlots, there will be a total of 54 paired artificial regeneration plots. Each 12 m² plot will be maintained free of understory competition to evaluate the canopy opening treatments. Each plot will be seeded with 20 acorns, planted with 4 bare-root seedlings (0.5 m tall) and planted with 3 bare-root saplings (>1.0 m tall). In total, 2,160 acorns, 432 seedlings and 324 saplings will be planted at the start of the first growing season after canopy treatment. At the end of each growing season, survival, diameter at 1.4 m and height of the seedlings and saplings will be measured, analyzed and summarized.

SUMMARY

Selective cutting as part of an uneven-aged forest management program may be used to restore and maintain a diversity of native woody vegetation in Category B woodlots at Gettysburg National Military Park. There is limited knowledge on the effects of various sized openings in the overstory canopy, with and without white-tailed deer, on the ground level vegetation. This project is being conducted to determine the potential for installing overstory treatments and to compose the specific treatments. Closed, small and large canopy openings treatments were assigned to replicated locations within each of the three study woodlots. Individual trees were designated to be felled to achieve the specific canopy treatments. Actual treatments to the study woodlots have been approval by the National Park Service. These treatments will be implemented prior to the 1993 growing season.

LITERATURE CITED

Cavanaugh, C. M. 1990. Identification, restoration, and maintenance of historic woodlots at Gettysburg National Military Park. Master of Forest Resources Paper, The Pennsylvania State University, University Park, PA. 119 p.

Fairweather, S. E. and C. M. Cavanaugh. 1990. Identification, restoration, and maintenance of historic woodlots at Gettysburg National Military Park. U. S. Department of Interior, National Park Service, Technical Report NPS/MAR/NRTR - 90/049, Philadelphia, PA. 123 p.

Gettysburg National Military Park. 1992. Evaluation of Alternatives for Managing the Appearance of Cropfields and Woodlots. U. S. Department of Interior, National Park Service, Gettysburg, PA. 26 p.

Otis, D. L., R. P. Burnham, G. C. White and D. R. Anderson. 1978. Statistical inference from capture data on closed animal populations. Wildlife Monograph 62. 135 p.

Seber, G. A. F. 1982. The estimation of animal abundance and related parameters. Charles Griffin and Co., High Wycombe, England. 654 p.

Roach, B. A. and S. F. Gingrich. 1968. Evenaged silviculture for upland central hardwoods. U. S. Department of Agriculture, Forest Service Handbook 335. 39 p.

Storm, G. L., D. F. Cottam, R. H. Yahner and J. D. Nichols. 1992. A comparison of 2 techniques for estimating deer density. Wildlife Society Bulletin 20:197-203.

Storm, G. L., R. H. Yahner, D. F. Cottam, and G. M. Vecello. 1989. Population status, movements, habitat use, and impact of white-tailed deer at Gettysburg National Historic Site, Pennsylvania. U. S. Department of Interior, National Park Service, Technical Report NPS/MAR/NRTR - 89/043, Philadelphia, PA. 513 p.

Storm, G. L. and A. S. Ross. 1992. Manual for monitoring plant communities: forests on public-owned lands in Mid-Atlantic United States. Pennsylvania Cooperative Fish and Wildlife Research Unit, MANV-00192. Pennsylvania State University, University Park, Pa. 89 p.

Storm, G. L. and W. M. Tzilkowski. 1992. Plant community development in historic woodlots in Gettysburg National Military Park. U. S. Department of Interior, National Park Service and Penn State University Cooperative Agreement 4000-9-8004. 5 p.

Tzilkowski, W. M., S. E. Fairweather, G. L. Storm and T. W. Bowersox. 1993. Forest regeneration and white-tailed deer at Gettysburg National Military Park. Proceedings of Seventh Conference on Scientific Research and Management in National Parks. (In press).

White, G. C., D. R. Anderson, K. P. Burham and D. L. Otis. 1982. Capture-recapture and removal methods for sampling closed populations. U. S. Department of Energy LA-8787. Los Alamos National Laboratory, NM. 235 p.

Deer Exclusion Effects on Understory Development Following Partial Cutting in a Pennsylvania Oak Stand

Larry H. McCormick[1], John W. Groninger[2], Kathy A. Penrod[1], and Todd E. Ristau[1]

Abstract: Forty fenced and unfenced paired plots were established in a central Pennsylvania mixed oak stand following an improvement shelterwood cut to assess the influence of deer exclusion on the establishment and development of understory vegetation during the first four years following cutting. Exclusion of deer increased the abundance and height growth of woody regeneration which consisted primarily of yellow-poplar, red maple, black birch and black gum. Few oak seedlings became established during the study in either the fenced or unfenced plots. Deer exclusion affected herbaceous composition and enhanced the abundance of woody vines and shrubs. Possible implications of deer exclusion following partial cutting on stand development and plant diversity following further overstory removal are discussed.

INTRODUCTION

Overpopulation of white-tailed deer has long been acknowledged as a problem in Pennsylvania (Frontz 1930, Leopold 1947, Marquis 1974). Protective laws and extensive clearcutting in the early 1900s led to a deer population explosion in the 1930s and 1940s (Marquis 1973). While efforts are being made to reduce the deer herd in Pennsylvania, deer densities remain high in many forested areas of the state (Pennsylvania Game Commission 1992).

Studies on the impact of deer browsing on forest regeneration following clearcutting show that height, abundance and composition of regenerating species are significantly affected (Shafer et al. 1961, Marquis and Brenneman 1981, Tilghman 1989, Trumbull et al. 1989). In northern Pennsylvania, browsing of unprotected clearcuts has led to regeneration failures characterized by inadequate stocking and dense communities of grasses, ferns, goldenrods and asters. Selective browsing in unprotected northern hardwood clearcuts has resulted in a reduction of sugar maple, pin cherry and blackberry while increasing the proportion of beech, birch, and striped maple (Marquis 1974).

Despite heavy deer browsing, most northern harwood stands in Pennsylvania can be successfully regenerated provided there is sufficient advance regeneration of adequate size prior to the final harvest cut (Grisez and Peace 1973, Marquis 1982, Marquis and Bjorkbom 1982). In stands without adequate advanced regeneration, a series of partial cuts are recommended to establish the necessary advanced regeneration prior to final overstory removal (Marquis et al. 1991). In addition electric fencing is being used increasingly to protect regeneration from browsing in Pennsylvania (Brenneman 1988, George et al. 1991).

---

[1] Associate Professor and Research Graduate Assistants, School of Forest Resources, The Pennsylvania State University, University Park, PA 16802.

[2] Graduate Research Assistant, Department of Forestry, Virginia Tech, Blacksburg, VA 24061.

While numerous studies have been conducted on the impact of deer browsing in northern hardwood stands in northern Pennsylvania, few studies of a similar nature have been conducted in oak stands in Pennsylvania. The purpose of this study was to examine the effect of deer browsing on the abundance, growth, species composition and diversity of understory vegetation following an improvement shelterwood cut in a central Pennsylvania mixed oak stand.

METHODS

Study Area

The study was conducted in a 100-year-old, even-aged, mixed oak stand on the Rothrock State Forest in the Ridge and Valley Province of central Pennsylvania. The 40 acre stand occupied a middle to lower slope position of a valley ridge with a southeast aspect. The site was moderately steep and rocky with sandstone talus predominant on the soil surface. Soil series found on this site include Andover, (fine-loamy, mixed, mesic, Typic Fragiaquults), Buchanan (fine-loamy, mixed, mesic, Aquic Fragiudults) and Hazleton (loamy, skeletal, mixed, mesic, Typic Dystrochrepts). Andover and Buchanan soils contain a fragipan and are classified as poorly drained and somewhat poorly drained respectively, whereas the Hazleton soil is classified as well drained with no fragipan (Merkel et al. 1978).

In spring 1989, the stand received an improvement shelterwood cut. Cutting reduced basal area from 100 to 80 ft^2/ac. Basal area measurements taken at the start of the 1990 growing season ranged from 30 to 110 ft^2/ac with an average of 80 ft^2/ac. Following the harvest cut, gypsy-moth related mortality reduced live basal area an additional 10 to 15% and contributed to added variation in canopy cover within the site. Basal area measurements taken in 1992 ranged from 40 to 155 ft^2/ac with an average of 86 ft^2/ac.

Dominant overstory tree species on the site before and after the cut were northern red, black, white and chestnut oak, yellow-poplar, and red maple. Some black gum and hickory occurred as intermediates. Few saplings and woody seedlings occurred in the stand prior to the cut. The understory contained scattered occurrences of blueberry, ferns, grasses, mosses and other perennial herbaceous and woody species. The stand was bordered to the southwest by a 5-year-old clearcut, to the northeast by a 200 acre seed-tree cut made in 1988, and to the southeast by an uncut area .

Although no direct measurements of the deer population on the site were made during the study, it is assumed the deer population was between 20 and 30 deer per square mile of forest land based on estimates by the Pennsylvania Game Commission for this portion of state. Visual sightings, evidence of browsing, and presence of deer pellets indicated the continued presence of deer on the site throughout the study. Other herbivorous and granivorous animals including gray and red squirrels, chipmunks, mice and birds were also observed on the site during the study, but their populations were not quantified.

Study Design

Forty fenced and unfenced paired plots were randomly established in the study area immediately following the improvement shelterwood cut in the spring of 1989. The fenced plots were enclosed by 4 ft. high galvanized steel hexagonal mesh (2 inch size openings) on four sides to exclude deer and other animals like rabbits but not mice or other small rodents. The exclosures, which were not covered on the top, were rectangular in shape and varied from 4 to 6 ft. wide and from 6 to 9 ft.

long. Inside each fenced area, vinyl stake flags were used to permanently mark two square grids (2.3 x 2.3 ft.) containing 5.3 ft^2 each. Two identical grids were established outside and adjacent to the fenced area to allow for paired comparisons of plots.

Based on surrounding stand density and extent of soil disturbance resulting from harvesting activities, the plots were classified as open, closed, or skidded. The open plots had basal areas less than 80 ft^2/ac. with no soil disturbance, the closed plots had greater than 80 ft^2/ac. basal area with no soil disturbance and the skidded plots generally had less than 80 ft^2/ac. and exposed mineral soil following the harvest cut. There were 9 open, 20 closed, and 11 skidded plots.

Regeneration data were recorded annually in 1989, 1990 and 1992 at the end of the first, second and fourth growing season following the harvest cut. The number of tree seedlings present in each grid was recorded by species and height class. Height classes for woody species in 1989 and 1990 were <1 inch, 1 - 6 inch, 6 - 12 inch and >12 inch, and in 1992 were <1 inch, 1 - 6 inch, 6 - 12 inch, 1 - 3 ft., 3 - 5 ft., and > 5 ft. Seedlings were not permanently identified for repeated measurement; instead, independent counts were taken each year. An estimate of percent cover for herbaceous species groups and woody shrub and vine species was also made. The herbaceous vegetation categories were grasses, tall herbaceous, herbaceous, ferns, and mosses and lichens. Blackberry, grape, blueberry, and mountain laurel were recorded by species. The height and species of the tallest tree (dominant tree) on each plot were recorded in 1992. The fenced and unfenced data for all variables were obtained by averaging the recorded values for the two grids in each fenced and unfenced plot. Paired t test comparisons of mean differences were used to test the effects of fencing on seedling abundance for each species using data for all plots combined. Similar comparisons were conducted by plot type (closed, open, and skidded). Analysis of variance procedures were used to test the effect of plot type on seedling abundance.

In 1992, data were collected to quantify the effects of deer exclusion after four years of regeneration on tree, woody shrub and vine, and herbaceous species diversity. Species richness and abundance were recorded for each of the two fenced grids and the two unfenced grids used for regeneration data collection. Species richness was defined as the number of different species present. Species abundance was recorded for each species as number of stems for tree species and by visual estimates of percent cover for shrubs, vines and herbaceous species.

Species richness (number of species present) and the Shannon index ($H' = -\Sigma p_i \ln p_i$, where p_i = number of individuals for species i divided by the total number of individuals for all species) were used to assess species diversity. Shannon's index was calculated for each plot using trees only and using all vegetation categories. A paired t test of mean differences was used to compare the Shannon index and species richness for the fenced and unfenced treatments by plot type (closed, open or skidded) and for all plot types combined.

RESULTS

At the end of the fourth growing season following harvesting, the most frequently occuring tree species comprising the regeneration on the fenced and unfenced plots were red maple, yellow-poplar, black birch, black gum, and oak species (northern red, black, white and chestnut). Red maple was found on all fenced and unfenced plots. Birch was found on 70% of the fenced and 65% of the unfenced plots. Yellow-poplar was found on 60% of fenced and 62% of unfenced plots. Black gum was present on 35% of fenced and 20% of unfenced plots. Oak species were found on 28% of fenced and 20% of unfenced plots. Other tree species occuring on the plots included sassafras, serviceberry, hawthorn, big-toothed aspen, alternate-leaved and flowering dogwoods, black cherry, pin cherry and eastern white pine.

Throughout the study, red maple was the most abundant tree species, followed by yellow-poplar, black birch, black gum and oaks (Table 1). For some tree species, fencing resulted in an increased number of seedlings. At the end of the first growing season, the number of red maple, oak and black gum seedlings per acre averaged over all plots was significantly higher ($p<.05$) in fenced plots. All of the trees recorded the first year were less than six inches. At the end of the second growing season, only red maple had a significantly higher average total number of seedlings per acre on the fenced plots. In the different height classes, the number of red maple, yellow-poplar, black birch and black gum seedlings in the 6 - 12 inch height class and the number of black birch and black gum seedlings over 1 ft. were significantly greater in the fenced plots. After four years, only the total number of red maple and oak seedlings were significantly higher on the fenced plots. The number of red maple in the 6-12 inch, 1-3 ft. and 3-5 ft. height classes were significantly higher in the fenced plots. Yellow-poplar had significantly lower numbers on fenced plots in the <1 inch and 1-6 inch height classes, and higher numbers in the 1-3 ft., 3-5 ft. and >5 ft. height classes. The number of black birch on the fenced plots were significantly higher in the 6-12 inch, 3-5 ft. and >5 ft. height classes.

Dominant tree species varied between fenced and unfenced plots after four years of growth. In the fenced plots, black birch was the dominant species in 45% of the plots followed by red maple (25%), black gum (12%) and yellow-poplar (10%). Sassafras and aspen were dominant in <5% of fenced plots. In the unfenced plots, red maple was the dominant species in 45% of the plots followed by birch (28%), and yellow-poplar (12%). Oak species were dominant in <5% of unfenced plots. The average height of dominant trees was 4.8 ft. for fenced plots and 0.6 ft. for unfenced plots.

With the exception of yellow-poplar, plot type did not have a significant effect on the total number of tree seedlings per acre. On both fenced and unfenced plots, the total number of yellow-poplar seedlings was significantly lower on closed plots than on open or skidded plots (Table 2). Plot type did have an effect on the number of seedlings per acre for most species in the taller height classes in the fenced plots. This was particularly true for yellow-poplar and black birch where the average number of seedlings in the 1-3 ft., 3-5 ft. and >5 ft classes were substantially higher in the fenced skidded and open plots than in the fenced closed plots. The same was true for red maple in the 1-3 ft. and 3-5 ft. classes.

Herbaceous species recorded in the grass category included poverty oats grass, sedges and other monocots. The tall herbaceous plant category was mostly fireweed and snakeroot, with loosestrife, goldenrod and aster species also included in this category. The herbaceous category included teaberry, false Solomon's seal, pearly- everlasting, violets, cinquefoil, sheep sorrel and other less common dicots. Hayscented fern was common on the site with New York fern present but sparse. Woody shrubs and vines were classified by species; those found were grape, blueberry, blackberry and mountain laurel.

Paired comparisons for the mean difference between fenced and unfenced percent cover for herbaceous species showed significantly lower percent coverage in all fenced plots for grasses and ferns (Figure 1). Grasses were also lower in skidded fenced plots. Grape had a higher average percent cover on all fenced plots and on skidded fenced plots. When grape, blueberry and blackberry were combined into a woody interference category, average percent cover was higher on all fenced plots. The herbaceous category was lower in closed fenced plots only.

The Shannon index measuring diversity of all vegetation categories combined including trees averaged 1.34 for fenced plots and 1.45 for unfenced plots. Differences in the Shannon index between fenced and unfenced plots were not significant. Species richness, however, was significantly higher in the unfenced plots. Species richness averaged 6.4 species for fenced plots and 7.3 species for unfenced plots. Diversity for all species combined was not significantly different between fenced and unfenced plots when the plots were analyzed by plot type (closed, open, skidded).

Table 1. Average number of tree seedlings per acre by height class one (1989), two (1990) and four years (1992) following harvesting.

		1989		1990					1992				
Species	Treatment	< 6"	< 6"	6"-12"	>12"	TOTAL	< 1"	1"-6"	6"-12"	1'-3'	3'-5'	> 5'	TOTAL
Oak sp. †	Fenced	2023 •	1214	1012	0	2226	0	1720	708	0	0	0	2428 •
	Unfenced	911	708	0	0	708	0	708	0	0	0	0	708
Yel poplar	Fenced	9510	9409	2732 •	5160	17301	202	3642	1821	3845 •	3541 •	3136 •	16187
	Unfenced	6070	11534	506	5160	17200	1518 •	6880 •	3946	911	0	0	13255
Red maple	Fenced	42695 •	35411	5160 •	1214	41785 •	911	35512	9207 •	7892 •	1315 •	0	54837 •
	Unfenced	27924	24180	101	0	24281	1821	28228	3035	607	0	0	33691
Bl birch	Fenced	4958	3136	1922 •	3541 •	8599	2124	2832	1315 •	2428	2125 •	1821 •	12645
	Unfenced	4350	2732	202	101	3035	2125	4755	3541	2226	0	0	12647
Black gum	Fenced	2428 •	304 •	809 •	1315 •	2428	101	708	304	1113 •	202	101	2529
	Unfenced	708	1012	202	0	1214	0	1315	506	0	0	0	1821
Other ††	Fenced	607	607	405	202	1214	0	607	304	607 •	405 •	304	2227
	Unfenced	607	708	202	0	910	0	1416	0	0	0	0	1416

• Difference between fenced vs unfenced significant at $p<0.05$.

† Oak species were black, northern red, white, and chestnut.

†† Others included sassafras, serviceberry, hawthorn, aspen, dogwood, black cherry, pin cherry and E. white pine.

Table 2.—Average number of seedlings per acre by height class for closed, open, and skidded plots in 1992.

CLOSED
n=20

Species		<1"	1"-6"	6"-12"	1'-3'	3'-5'	>5'	TOTAL
Oak sp. †	F †††	0	2234	1416	0	0	0	3650
	U	0	1012	0	0	0	0	1012
Yel-poplar	F	405	2631	1012	1012	405	0	5465
	U	607	5868	3440	607	0	0	10522
Red maple	F	809	48969 *	9713 *	4047 *	0	0	63538 *
	U	1012	34400	1211	405	0	0	37030
Bl birch	F	3642	3035	1821	2428	1619	1012	13557
	U	2428	4856	2631	1214	0	0	11129
Black gum	F	202	1012	202	1416	202	202	3238
	U	0	2024	607	0	0	0	2631
Other ††	F	0	405	202	405	0	0	1012
	U	0	607	0	0	0	0	607

OPEN
n=9

Species		<1"	1"-6"	6"-12"	1'-3'	3'-5'	>5'	TOTAL
Oak sp. †	F	0	735	0	0	0	0	735
	U	0	367	0	0	0	0	367
Yel-poplar	F	0	1349	2248	5846	11242	10792 **	31477
	U	1349	6745	5396	1799	0	0	15289
Red maple	F	450	19785	12141 *	18436 *	5396	0	56208 *
	U	2248	19336	4497	1349	0	0	27430
Bl birch	F	736	3311	736	4047	3679	3311	15020
	U	1840	3679	4047	2575	0	0	12141
Black gum	F	0	899	899	1349	450	0	3597
	U	0	899	899	0	0	0	1798
Other ††	F	0	405	202	405	0	0	1012
	U	0	607	0	0	0	0	607

SKIDDED
n=11

Species		<1"	1"-6"	6"-12"	1'-3'	3'-5'	>5'	TOTAL
Oak sp. †	F	0	367	0	0	0	0	367
	U	0	367	0	0	0	0	367
Yel-poplar	F	0	7358	2943	7358 *	2207 *	2575	22441
	U	3311	8830	3679	736	0	0	16556
Red maple	F	1472	23914	5887	6254 *	368	0	37895
	U	2943	24282	5151	368	0	0	32744
Bb birch	F	736	3311	736 *	4047	3679 *	3311 *	15820
	U	1840	3679	4047	2575	0	0	12141
Black gum	F	0	0	0	368	0	0	368
	U	0	368	0	0	0	0	368
Other ††	F	0	0	736	1472 *	368	736	3311
	U	0	4899	0	0	0	0	4899

* Difference in fenced vs unfenced significant at $p<0.05$.

† Oak species were black, northern red, white, and chestnut.

†† Others included sassafras, serviceberry, hawthorn, aspen, dogwood, black cherry, pin cherry, and E. white pine.

††† F- Fenced, U- Unfenced.

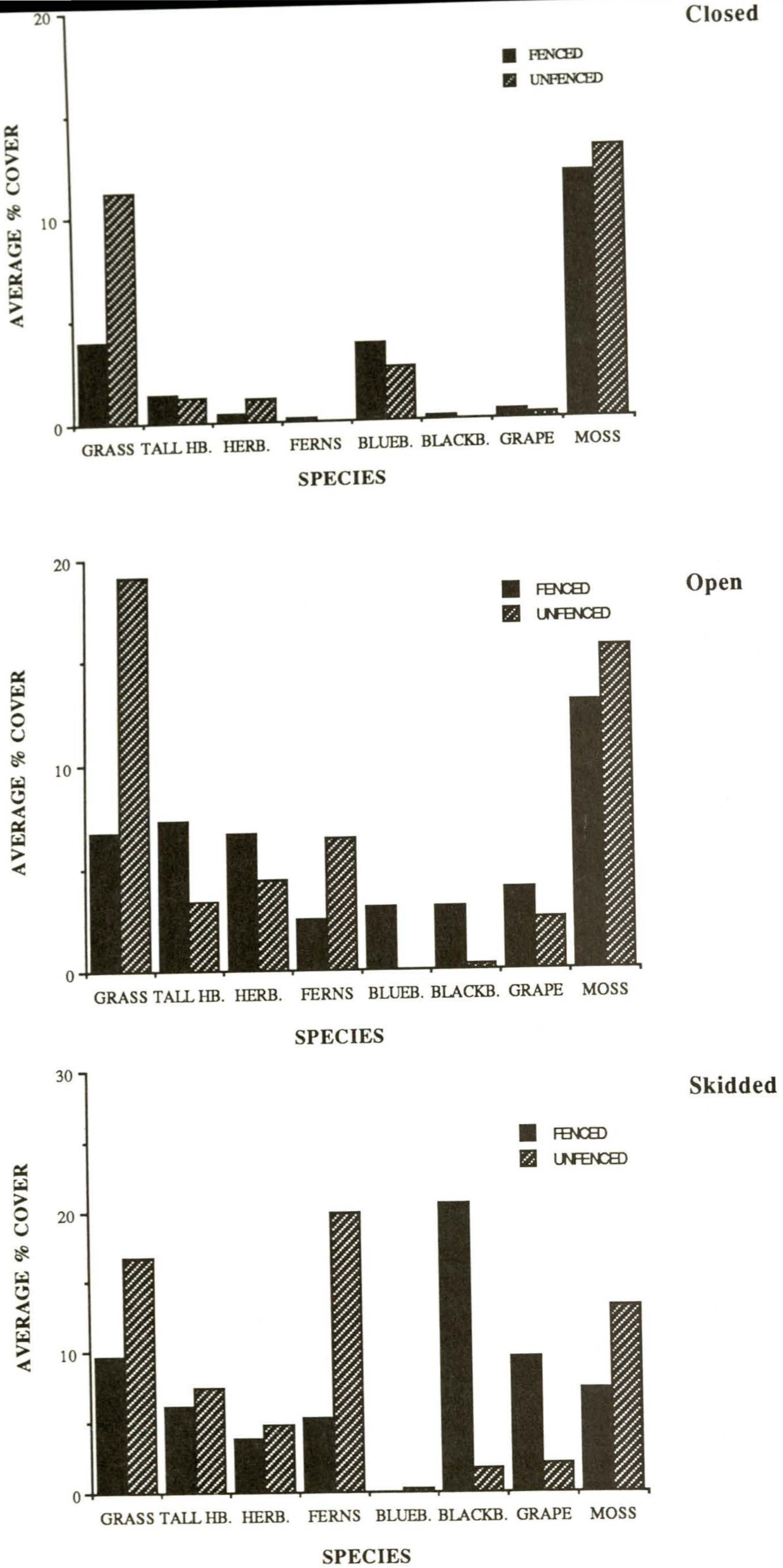


Figure 1.—Percent cover for herbaceous species on fenced and unfenced closed, open and skidded plots.

Diversity also was determined for tree regeneration alone. The Shannon index values were 0.77 for unfenced plots and 0.81 for fenced plots. Species richness averaged 3.3 species for fenced plots and 2.8 species for unfenced plots. Species richness was significantly higher for fenced plots, but the Shannon indices were not significantly different between the two treatments. Diversity for tree regeneration was not significantly different between fenced and unfenced plots when the plots were analyzed by plot type (closed, open, skidded).

DISCUSSION

Results of this study indicate that deer browsing affected the abundance, growth, species richness and diversity of regeneration in this partial cut mixed oak stand in central Pennsylvania. Elimination of deer browsing through fencing resulted in a significantly greater number of seedlings per acre for some tree species. Most notable were the increased numbers of red maple seedlings in the fenced plots. At the end of the fourth growing season, the total number of red maple seedlings per acre in the fenced plots was one and one-half times greater in the unfenced plots. The number of oak seedlings also was significantly higher in the fenced plots after four years, however, they represented only a small portion of the woody regeneration.

In addition to affecting the abundance of some tree species, elimination of deer browsing allowed for increased height growth of many species and resulted in a shift of height class distribution between the fenced and unfenced plots. With the exception of oak, all the major tree species in the regeneration advanced to heights over three feet inside the fences. This was not true outside of the fence, where no seedlings of any species exceeded 3 feet in height. This supports other studies where fencing was found to increase height growth (Marquis 1974, Shafer et al 1961, Tilghman 1989, and Trumbull et al. 1989). Tilghman's (1989) study found that in thinned Allegheny hardwood stands the tallest trees in low deer density areas were twice as tall as those in the high deer density areas.

Species richness for trees was significantly higher in fenced plots. This was likely due to the selective feeding by deer. Fencing protected those species that were more palatable. All of the tree species found occurred on both fenced and unfenced plots. However, the number of species in most cases was greater inside the fences resulting in a higher average richness. The herbaceous component of the understory differed for fenced and unfenced plots. Ferns and grasses were more abundant outside fences. Tilghman (1989) and Trumbull (1989) each found similar increases for ferns and grasses repectively, and decreases in blackberry outside of fences. Although this study didn't have a significant difference, blackberry also was more abundant in the fences. Grape also was more abundant in fenced plots due to browsing outside of fences. Inside the fences dominance by woody vegetation likely limited the presence of grasses, ferns, and other species of herbaceous vegetation.

This study also suggests a future change in the species composition of the stand. Based on the species composition of the advanced regeneration, the next stand to occupy will likely be composed of red maple, yellow-poplar, black birch, black gum and other hardwoods irrespective of whether or not the regeneration is protected from deer browsing. Oak will likely be a minor component in the next stands due to its low abundance and slow growth. Lorimer (1984) also found a replacement of oak stands by red maple in four upland oak forests in Massachusetts and New York, with understories of dense red maple and very sparse representation from the oaks. The reason(s) for the replacement of oak stands by other hardwoods is not fully understood. Abrams and Nowacki (1992) reported that repeated cutting and burning of the original oak-pine forests following European settlement increased the relative dominance of oak at least for the short term. They attributed the successional progression of the oak forests to red maple to a drastic reduction in logging and fire in this century and noted that logging of these stands with understories dominated by red maple results in recruitment of these species into the canopy instead of the oaks. This also seems to be the case for the forest stand studied here. The browsing of white-tailed deer, the competition by herbaceous species and the reduced fire and logging in this century reduce the probability of regenerating oak stands to oak.

Results of this study indicate that the protection of partially cut oak stands in central Pennsylvania from deer browsing will likely increase the success of stand regeneration by allowing the development of advanced reproduction of sufficient size and abundance. Exclusion of deer browsing, however, will not insure the reestablishment of oak as the dominant species. It appears that in the future many of the current oaks stands will become mixed hardwood stands containing a large component of red maple.

ACKNOWLEDGEMENTS

The authors wish to thank David George, Tracy Hippensteel, and Durland Shumway for their valuable assistance in conducting this research.

LITERATURE CITED

Abrams, M. D. and G. J. Nowacki. 1992. Historical variation in fire, oak recruitment, and post-logging succession in central Pennsylvania. Bull. Torrey Bot. Club 199(1): 52-61.

Brenneman, R. E. 1988. Controlling deer problems in hardwood stands. In Proceedings: Guidelines for Regenerating Applachian Hardwood Stands. Morgantown, WV p. 97-103.

Frontz, L. 1930. Deer damage to forest trees in Pennsylvania. PA. Dep. For. and Waters Res. Circ. No. 3. 10p.

George, D. W., T. W. Bowersox, and L. H. McCormick. 1991. Effectiveness of electric deer fences to protect planted seedlings in Pennsylvania. pp. 395-401. In Proceedings 8th Central Hardwood Conference. USDA For. Serv. Gen. Tech. Rpt. NE-148.

Grisez, T. J. and M. R. Peace. 1973. Requirements for advance reproduction in Allegheny hardwoods - an interim guide. USDA For. Serv. Res, Note NE-180. 5p.

Leopold, A., L. K. Sowls, and D. L. Spencer. 1949. A survey of over-populated deer ranges in the United States. J. Wildl. Manage. 2: 162-177.

Lorimer, C. G. 1984. Development of the red maple understory in northeastern oak forests. For. Sci. 30(1): 3-22.

Marquis, D. A. 1973. Pennsylvania's Allegheny hardwoodforests: their bounty of timber and deer are the results of events that occurred many years ago. Pa. For. 63(4):88-89, 109-112.

Marquis, D. A. 1974. The impact of deer browsing on Allegheny hardwood regeneration.. USDA For. Serv. Res. Pap. NE-308. 8p.

Marquis, D. A. 1982. Effect of advance seedling size and vigor on survival after clearcutting. USDA For. Serv. Res. Pap. NE-498. 7p.

Marquis, D. A., R. L. Ernst and S. L. Stout. 1991. Prescribing silvicultural treatments in hardwood stands of the alleghenies (Revised). USDA For. Serv. Tech. Rept. NE-96.

Marquis, D. A. and J. C. Bjorkbom. 1982. The impact of deer on forest vegetation in Pennsylvania. USDA For. Serv. Gen. Tech. Rep. NE-65.

Marquis , D. A. and R. Brenneman. 1981. The impact of deer on forest vegetation in Pennsylvania. USDA For. Serv. Res. Pap. NE-65.

Merkel, E. J. , T. J. Craft and G. D. Yoder. 1978. Soil survey of Huntingdon County, Pennsylvania. USDA Soil Conservation Service.

Pennsylvania Game Commission. 1992. 1991-1992 deer harvest. PA Game News. 63(5): 37-39.

Shafer E. L. Jr., T. J. Grisez and E. Sowa. 1961. Results of deer exclosure studies in northeastern Pennsylvania. USDA For. Serv. Res. Notes No. 121. 7p.

Tilghman, N. G. 1989. Impacts of white-tailed deer on forest regeneration in northwestern Pennsylvania. J. Wildl. Manage. 53(3): 524-532.

Trumbull, V. L., E. J. Zielinski, and E. C. Aharrah. 1989. The impact of deer browsing on the Allegheny Forest Type. North. J. Appl. For. 6: 162-165.

Lease Hunting in the Central Hardwood Region: An Examination of Tradeoffs

Stephen M. Bratkovich and Donald W. Floyd[1]

Abstract: An examination of literature pertaining to lease (fee) hunting resulted in a description of tradeoffs for landowners, hunters, wildlife managers, and wildlife in the Central hardwood forest region. Landowner advantages associated with a lease hunting enterprise were better vandalism and trespass control, increased income, increased services, enhanced wildlife management, and farmland preservation; disadvantages were increased landowner liability, increased time and financial investment, changes in farm operation, and increased resentment. Advantages of lease hunting to hunters, wildlife managers, and wildlife were increased wildlife management, reduced hunting pressure on private land, and reduced hunter/landowner conflicts; disadvantages for these groups were increased hunting pressure on public lands, increased hunting expense, and conversion of hunting into a sport only for the wealthy. A possible consequence of lease hunting in the Central hardwood forest region is discussed. Recommendations are provided to Central hardwood forest and wildlife managers regarding the relationship between lease hunting, landowner attitudes, and private forestland management.

INTRODUCTION

Over 60% of the 2.4 billion acres in the United States are privately owned. Central hardwood forest states such as Illinois, Indiana and Ohio, for example, have percentages of private land ownerships much higher than the national average (Hackett 1989). Consequently, a large proportion of wildlife-related recreation takes place on private farms and forests. Nationally, approximately 82% of all hunting in 1985 occurred on private land (USDI Fish and Wildlife Service 1988).

In recent years, the concept of landowners seeking compensation for providing hunting access has increased in popularity. Two concurrent trends have contributed to private landowners investigating the potential of their property for a lease (fee) hunting enterprise (Rasker et al. 1991). The first is an increased demand for outdoor recreation. A 1962 prediction that the demand for outdoor recreation would triple by the year 2000 was realized by 1983. The President's Commission on Americans Outdoors (1987) recommended that ways be found to stimulate the private sector to provide recreational opportunities.

The second (long-term) trend is the agricultural sector "slow down". The 1980's farm economy was characterized by low agricultural prices, high costs of production, and increased international competition. Long-term trends indicate that there is no longer the same high rate of agricultural expansion seen between the mid-1950's and the mid-1970's.

Over one-half of all lease hunting in the U. S. occurs in six southern states: Texas, Georgia, Louisiana, Virginia, Alabama, and Mississippi (Shelton 1989). The proportion of private land leased in the South for recreational access (which includes hunting) more than doubled between 1981 and 1987 (Guynn 1989). Even though lease hunting in Central hardwood forests is relatively small compared to the South, its adoption will likely increase in the near future. The purpose of this paper is to (1) summarize the literature on the advantages and disadvantages of lease hunting, (2) discuss a possible consequence of lease hunting in the Central hardwood region, and (3) provide recommendations to Central hardwood forest and wildlife managers regarding the relationship between lease hunting, landowner attitudes, and private forestland management.

---

[1] Marketing Specialist, USDA Forest Service, State and Private Forestry, 1992 Folwell Ave., St. Paul, MN 55108, and Assistant Professor, Natural Resources, 2021 Coffey Rd., The Ohio State University, Columbus, OH 43210.

WHAT IS LEASE HUNTING?

Lease hunting is an arrangement whereby the landowner grants the right of ingress (access) on his/her property (for a specified time period) to the hunter, for the purpose of hunting in exchange for services, goods or a fee. The right to control access to private land is a property right of all landowners.

"Shooting preserves", where animal populations (exotic or native) are increased through a stocking program are not addressed in this paper. Also, no mention will be made of raising game for commercial markets.

In the United States, lease hunting is a controversial topic. State governments control the right of possession of wildlife and landowners control the right of access to land ("split estate" problem). Arguments continue to surface on the issue of whether it is right to have to pay to hunt publicly-owned game on private property.

One viewpoint is that, "Paid hunting...reduces the public's interest in wildlife, [and] hands wildlife to a wealthy minority for their exclusive use" (Geist 1988). Others have argued for many years that, "As the farmer sees the picture, he feeds, raises and protects the game, the state claims it and the sportsman gets it, while he gets only crop depredations and trespass problems" (Howard and Longhurst 1956).

A listing of all the legal, historical and philosophical reasons for or against lease hunting is beyond the scope of this paper. It is important to recognize though that many differences do exist.

TRADE-OFFS FOR WILDLIFE, WILDLIFE MANAGERS AND HUNTERS

Whenever lease hunting is practiced, three groups, in addition to landowners, are potential winners and losers - wildlife, wildlife managers and hunters.

Studies in Montana (Lacey et al. 1988) and Oregon (Rasker et al. 1991) found that landowners who lease land tend to invest more in habitat and management practices than landowners who do not lease. Therefore, all of the above groups may receive benefits from lease hunting if landowners who lease land tend to practice better wildlife management. Increased landowner demand for wildlife management assistance will generate increased demand for the expertise of wildlife managers. Wildlife managers also benefit when landowners furnish detailed harvest data from their land that would otherwise not be available for decision-making.

A survey of all 50 state wildlife divisions/departments found that 19 agencies reported wildlife had increased on leased lands with no agency reporting a wildlife decline on leased land (Wiggers and Rootes 1987). Lease hunting can have a negative impact however when a high percentage of previously "open land" is leased, resulting in hunting pressure increasing dramatically on state wildlife management areas (Smith 1988). This can result in an uneven distribution of wildlife populations and unsatisfactory harvests with the wildlife manager "pressured" to alleviate the resource management conflict.

From a hunter's perspective, lease hunting provides a reserved, uncrowded hunting area. It also makes hunters more aware of their conduct and that of fellow hunters, since careless actions can deny them further entry to the property. Therefore, fewer landowner-hunter conflicts should result in more access to private land (Wildlife Management Institute, undated) which will also be a benefit to wildlife managers.

Purchasing a hunting lease makes hunting more expensive. Also, as lease hunting becomes more common, fewer private tracts may be available to the general public. Thus, lease hunting has the potential of converting hunting into a sport for the wealthy (Fitzhugh 1988, Geist 1988).

TRADE-OFFS FOR LANDOWNERS - ADVANTAGES

Landowners may receive several benefits from implementing lease hunting practices. Many landowners are able to improve trespass control, increase income, manage wildlife populations and preserve their farm by implementing lease hunting as an alternative land use.

Vandalism and Trespass Control

Vandalism has been reduced and better trespass control obtained through lease hunting (Rasker et al. 1991, Shelton 1981). More than 60% of landowners using leases do so to control access (USDA 1987). A perceived need by landowners to "regulate" hunting on private land may explain why 53% of surveyed landowners in Virginia post their property, while only 10% prohibit hunting (Bromley and Hauser 1984).

Increased Income

The U. S. Fish and Wildlife Service (1988) reported that hunters paid landowners $77.8 million in access fees in 1985. Gross returns to individual landowners will vary but white-tailed deer leases, for example, have ranged between $2 to $10 per acre per year (Wiggers and Rootes 1987) with an average in the South of less than $3 per acre per year (Lassiter 1985, Marsinko et al. 1992, Melchiors 1989). A 1979 Colorado survey reported that 78% of non-residents and 48% of resident hunters would consider paying fees to hunt (Benson 1983). A Kansas study revealed that 35% of the hunters approved of lease hunting with the majority believing they would not change their habits drastically should lease hunting become widespread (Maier and Karim 1987). Therefore, increased landowner income from a hunting lease operation is a viable possibility based on existing lease rates and a willingness from a certain percentage of hunters to support the concept.

Increased "Other" Services

Many hunting clubs that lease land from private landowners invest large sums of money in road development, graveling, culverting, fence building, patrolling, etc., that benefit landowners. Landowners often barter for free services such as medical, dental, tire repair, discounts on trucks/cars/guns, etc., which are provided in lieu of, or in addition to, monetary returns (Shelton 1981).

Enhanced Wildlife Management

Lease hunting arrangements can include wildlife management plans for controlling numbers and quality of wildlife, particularly deer. Leases can be specific, directing attention at some game species and protecting others. Also, the number of hunters can be controlled, as well as where they hunt (Bromley 1988, Davis and Benson 1992).

Farmland Preservation

Even during the years of agricultural expansion (1970's), agricultural land in the U. S. was being converted to non-agricultural use at the rate of 3-million acres per year (Coughlin and Keene 1980). In Florida, for example, spiraling population growth has put tremendous pressure on farms and other undeveloped lands to be converted into housing developments, shopping centers, etc. Increased income via lease hunting can turn a marginal farm into a profitable one in certain instances, thus preserving the farm (Miller 1988, Smith 1988).

TRADE-OFFS FOR LANDOWNERS - DISADVANTAGES

Lease hunting is not a feasible alternative for some landowners. As with any alternative land use, it requires additional investment in management effort.

Liability Status

An increase in landowner liability is a major reason why lease hunting often has failed to develop into an economic enterprise (Dudderar 1981). Landowners participating in a national Agricultural Stabilization Conservation Service's Pilot Public Access Program indicated that liability was a significant concern (Kaiser and Wright 1985).

The level of legal responsibility is greatest when a fee is paid in exchange for the privilege of access. In reality, however, incidents of hunters suing landowners are uncommon (Yarrow et al. 1989).

Increased Time and Money Investment

Operating a lease hunting enterprise as a business requires careful management to make it profitable. Careful management requires a commitment of time and money. Machinery time, the expense of establishing and maintaining wildlife habitat and eliminating hazardous conditions are just a few items that require a time and money investment. If a business commitment is not made, then the lease hunting enterprise is just a sideline which tends to make it non-profitable (Bromley and Benson 1987, Fitzhugh 1987).

Changes in Farm Operation

Entertaining the public may require changes in the farm operation to prevent conflicts with other uses or land management practices. Charging for hunting access may mean changing the way the farm owner and relatives, neighbors and friends hunt on the farm (Bromley and Benson 1987).

Increased Resentment

Relatives, neighbors, friends and hunters may have ill-feelings and resentment since land formerly hunted upon for free is now managed under a lease arrangement. Landowners leasing land in Florida, for example, expressed a fear of vandalism and/or potential "burning out" by disgruntled local residents (Marion and Gates 1988).

DISCUSSION AND RECOMMENDATIONS

From a forester's perspective, a positive consequence of an increase in lease hunting in the Central hardwood region is the potential forest management spin-off from enhanced wildlife management.

For example, hardwood cutting practices to improve habitat for deer, turkey, and grouse often enhance the forest for timber products such as sawlogs and pulpwood. Since private non-industrial landowners in the Central hardwood region tend to own forestland for non-timber purposes (Birch 1982, Brooks and Birch 1986, Kingsley et al. 1988, Marty et al. 1988, Young et al. 1985), wildlife management via lease hunting could be the incentive to induce landowners to adopt management practices that benefit the wildlife and the timber resource. A recommendation is that foresters and wildlife managers become knowledgeable about lease hunting and assist landowners in investigating the feasibility of establishing a lease hunting enterprise.

Since few existing landowners in the Central hardwood region currently lease hunting rights, few early adopters (role models and opinion leaders) are available to assist potential entrepreneurs. In addition, while there is a wealth of literature nationwide on the subject of gross financial returns from leasing, little information has been published on private non-industrial forestland net returns (i.e., profitability) from leasing. Increased liability and an unknown hunter demand for leased land are also potential barriers to private land leasing. Therefore, even though resource managers might recognize the potential for better wildlife and forest management, disincentives still exist that will likely delay the rapid adoption of lease hunting by private landowners in the region. A recommendation, therefore, is that state wildlife agencies in the Central hardwood region develop pilot leasing programs on private land on an experimental basis. The pilot programs should be coordinated with various agencies and stakeholders (state forestry agencies, Cooperative Extension Service, Soil Conservation Service, U. S. Forest Service, local sportsman's clubs, etc.) and should have a goal of examining not only the potential profitability of lease hunting but the value of lease hunting as a wildlife and forest management tool.

The vast majority of research cited in this paper was generated outside of the Central hardwood region. Additional lease hunting research is needed in the region before in-depth technology transfer and educational programs can be implemented. Research questions that need to be addressed include, but are not limited to:

1. Who are the forest landowners most likely to adopt lease hunting on their property? (Farmers?, industrial owners?, absentee owners?, resident owners?, etc.)
2. What are the personal characteristics of landowners most likely to adopt (age, income, education, etc.) and how can they be identified?
3. What is the demand for lease hunting in the region and what are the characteristics of hunters most likely to lease land?
4. What are the acreage (tract size) requirements needed to operate a successful lease hunting enterprise? How much will the acreage requirements vary by distance from urban areas, proximity to public hunting areas, abundance of wildlife species, etc.?
5. What are the projected costs and returns of operating a lease hunting enterprise in the Central hardwood region? What are the likely scenarios of profitable and non- profitable enterprises?

In sum, lease hunting in the Central hardwood region is a move in the direction of multiple use which can result in more complete utilization of the forestland resource. However, lease hunting will undoubtedly remain controversial due to traditional values and the "split estate" problem. Forest and wildlife managers are encouraged to be objective and forthright in discussing with landowners the positive and negative tradeoffs of this alternative land use.

LITERATURE CITED

Benson, D. E. 1983. Wildlife as a farm and ranch business. Colorado State Univ. Ext. Serv. Publ. No. 6.514. Ft. Collins, CO. 2 p.

Birch, T. W. 1982. The forest-land owners of Ohio - 1979. USDA For. Serv. Resour. Bull. NE-74. 84 p.

Bromley, P. T. 1988. Personal communication.

Bromley, P. T., and D. E. Benson. 1987. Supplemental income from wildlife on your land. Virginia Coop. Ext. Serv. Publ. No. 420-095. Blacksburg, VA. 2 p.

Bromley, P. T., and T. G. Hauser. 1984. Hunter access to private lands in Piedmont, Virginia. P. 266-271 *In* Proc. Symp. Annual Conf. of SE Assoc. of Fish and Wildl. Agencies.

Brooks, R. T., and T. W. Birch. 1986. Opportunities and constraints for wildlife habitat management on private forests of the Northeast. No. J. Applied Forestry 3:109-113.

Coughlin, R. E., and J. C. Keene. 1980. National agricultural lands study: The protection of farmland. U. S. Gov. Printing Office, Washington, D. C.

Davis, R. K., and D. E. Benson. 1992. An evaluation of Colorado's ranching program for indigenous wildlife. *In* Proc. Symp. 3rd Int. Game Ranching. Pretoria, S. A. 27 p.

Dudderar, G. R. 1981. Dollars from wildlife. *In* Proc. Symp. National Ext. Wildl. and Fisheries Workshop. LA Coop. Ext. Serv.

Fitzhugh, E. F. 1987. Hunter's attitudes in California compared with fees and expenditures for private lands hunting. P. 141-145 *in* Proc. Symp. International Ranchers Roundup. Texas A & M Univ.

Fitzhugh, E. L. 1988. What can we learn from California's ranching for wildlife program? P. 69-73 *in* Proc. Symp. Recreation on rangelands - promises, problems, projections.

Geist, V. 1988. How markets in wildlife meat and parts, and the sale of hunting privileges, jeopardize wildlife conservation. Cons. Biol. 2:15-26.

Guynn, D. C., Jr. 1989. Fee hunting on private lands in the South: Synopsis, conclusions, and future directions. P. 149-155 *in* Proc. Symp. Fee hunting on private lands in the South, Yarrow, G. K., and D. C. Guynn, Jr. (eds.). Clemson Univ. Ext. Serv.

Hackett, E. 1989. The relationship between agencies, wildlife users and wildlife resources. P. 64-71 *in* Proc. Symp. Fee hunting on private lands in the South, Yarrow, G. K., and D. C. Guynn, Jr. (eds.). Clemson Univ. Ext. Serv.

Howard, W. E., and W. M. Longhurst. 1956. The farmer-sportsman problem and a solution. Trans. N. Am. Wildl. Conf. 21:323-331.

Kaiser, R. A., and B. A. Wright. 1985. Recreational access to private land: Beyond the liability hurdle. J. Soil and Water Cons. Nov/Dec:478-481.

Kingsley, N. P., S. M. Brock, and P. S. Debald. 1988. Focus group interviewing applied to retired West Virginia nonindustrial private forest landowners. No. J. Applied Forestry 5:198-200.

Lacey, J. R., S. B. Laursen, J. C. Gilchrist, R. M. Brownson, J. Anzick, and S. Doggett. 1988. Economic and social implications of managing wildlife on private land in Montana. Northwest Sci. 62:1-9.

Lassiter, R. L., Jr. 1985. Access to and management of the wildlife resources on large private timberland holdings in the southeastern United States. College of Business Adm. Monogr. No. 1, Tenn. Technol. Univ., Cookeville, TN. 253 p.

Maier, P. A., and M. Karim. 1987. How do some Kansas sportsmen and landowners feel about lease hunting? Kansas State Univ. Coop. Ext. Serv. Misc. Publ. Manhattan, KS. 16 p.

Marion, W. R., and C. A. Gates. 1988. Hunting lease arrangements in Florida and the Southeast. Florida Coop. Ext. Serv. Circular 793. Gainesville, FL. 19 p.

Marsinko, A. P., W. M. Smathers, Jr., D. C. Guynn, Jr., and G. L. Stucky, Jr. 1992. The potential economic effect of lease hunting on forest management in the Southeast. So. J. Applied Forestry 16:200-203.

Marty, T. D., W. B. Kurtz, and J. H. Gramann. 1988. PNIF ownerattitudes in the midwest: A case study in Missouri and Wisconsin. No. J. Applied Forestry 5:194-197.

Melchiors, M. A. 1989. Wildlife and fee hunting on forest industry lands in the South: A Weyerhaeuser company perspective. P. 99-106 *in* Proc. Symp. Fee hunting on private lands in the South, Yarrow, G. K., and D. C. Guynn, Jr. (eds.). Clemson Univ. Ext. Serv.

Miller, O. 1988. From beans to birds. Turkey Call, March/April:50-52.

President's Commission on Americans Outdoors. 1987. Americans outdoors: The legacy, the challenge. Island Press, Washington, D. C. 426 p.

Rasker, R., R. L. Johnson, and D. Cleaves. 1991. The market for waterfowl hunting on private agricultural land in western Oregon. Res. Bull. 70, College of For., Oregon State Univ. 14 p.

Shelton, R. 1981. Fee hunting in Mississippi. *In* Proc. Symp. National Ext. Wildl. and Fisheries Workshop. LA Coop. Ext. Serv.

Shelton, R. 1989. Fee hunting systems and important considerations. P. 24-32 *in* Proc. Symp. Fee hunting on private lands in the South, Yarrow, G. K., and D. C. Guynn, Jr. (eds.). Clemson Univ. Ext. Serv.

Smith, F. 1988. Personal communication with Florida Bureau of Wildlife Land Management staff member.

USDA. 1987. Estimating prices for access to opportunities for hunting, fishing, and viewing wildlife on public and private lands. Natural Resources and Environment Steering Comm. Report. Washington, D. C. 26 p.

USDI Fish and Wildlife Service. 1988. The 1985 national survey of hunting, fishing and wildlife-associated recreation. U. S. Gov. Printing Office, Washington, D. C. 167 p.

Wiggers, E. P., and W. A. Rootes. 1987. Lease hunting: Views of the nation's wildlife agencies. Trans. N. Am. Wildl. and Natur. Resour. Conf. 52:525-529.

Wildlife Management Institute. Undated. Improving access to private land. Washington, D. C. 15 p.

Yarrow, G. K., D. C. Guynn, Jr., and B. S. Mabry, Jr. 1989. Liability and fee hunting: Landowner concerns. P. 42-46 *in* Proc. Symp. Fee hunting on private lands in the South, Yarrow, G. K., and D. C. Guynn, Jr. (eds.). Clemson Univ. Ext. Serv.

Young, R. A., M. R. Reichenbach, and F. H. Perkuhn. 1985. PNIF management: A social-psychological study of owners in Illinois. No. J. Applied Forestry 2:91-94.

The Effects of Pruning Treatments and Initial Seedling Morphology on Northern Red Oak Seedling Growth

Donald J. Kaczmarek and Phillip E. Pope[1]

Abstract: Northern red oak (Quercus rubra L.) seedlings exhibit relatively high survival rates following planting, but their growth rates are often slow and extensive stem dieback can occur. This study was designed to investigate the growth responses of northern red oak seedlings planted with or without root-pruning or shoot-pruning. One-year-old (1-0) northern red oak nursery stock was planted without top-pruning while the two-year-old (2-0) stock was top-pruned to a shoot length of 25 cm. Both types of seedlings were planted with or without root-pruning. Morphological characteristics of each seedling were measured prior to planting to relate growth to a single or multiple morphological traits. Seedlings which were shoot-pruned had positive height growth during the first growing season and larger seedlings had greater growth than smaller seedlings. Seedlings not shoot-pruned showed varying degrees of stem dieback and larger seedlings had greater stem dieback than smaller seedlings. After one growing season, a subsample of the seedlings was excavated to evaluate root growth. Shoot-pruning reduced seedling root growth and root regeneration compared to non shoot-pruned seedlings. Although shoot-pruning reduced stem dieback, it also reduced seedling root growth

INTRODUCTION

There is increasing interest in the artificial regeneration of oak species in the eastern United States. The number and size of oak plantings have increased as marginal farmlands are converted to forest plantations. Increased emphasis has also been placed on securing oak regeneration on high quality forested sites. On these sites, oaks are often the dominant species in the overstory, but advance oak reproduction is sparse or lacking. Enhancement planting of oak seedlings is an alternative if natural regeneration is lacking or sparse.

Oak plantings, whether located on former agricultural lands or in forest situations often share two characteristics. Initial seedling survival is usually high, but growth rates are often slow (Hilt, 1977, Loftis, 1979, Loftis and McGee, 1986). Natural oak regeneration often exhibits a pattern of recurrent shoot dieback while forming an extensive root system. When a sufficient root system is established, oak stump sprouts are capable of rapid growth rates (Cobb et al., 1985). This would suggest that root-to-shoot ratios may control the growth of oak regeneration.

This study was implemented to determine the influence of shoot and root-pruning treatments on the growth of northern red oak seedlings on old field sites. Correlation analysis was used to determine the relationship between initial seedling morphological characteristics and subsequent growth of seedlings in the various pruning treatments. Seedlings were excavated after 1 growing season to determine the effects of cultural treatments on root development and growth.

---

[1] Graduate Research Assistant and Professor, respectively, Department of Forestry and Natural Resources, Purdue University, West Lafayette, IN 47907. Purdue Agric. Experiment Stn. No. 13,700.

METHODS

The planting site selected for this study is located in Tippecanoe County in west-central Indiana. This area is classified as the Entrenched Valley Section of the Central Till Plain Natural Region (Homoya et al., 1985). The site is a former agricultural field in the early stages of old-field succession. This situation is common for oak plantings across the state of Indiana. The soil is a Fincastle silt-loam (fine-silty, mixed, mesic Aeric Ochraqualf) with a site index for northern red oak of 75 feet at a base-age of 50 years (Soil Conservation Service, unpublished data). The planting was enclosed in an electrical fence to reduce deer damage to the seedlings.

All seedlings used in this study were obtained from Indiana's Jasper-Pulaski State Nursery in Medaryville, Indiana and were at least 30 cm in height with a root-collar diameter of at least 6 mm. All seedlings used in this study were lifted in the fall of 1991 and stored in cold-storage at temperatures of 2-5ºC. Seedling root systems were maintained in moist sphagnum moss from lifting to planting. The field planting took place on May 4, 1992. Soil conditions were dry enough to permit easy planting and refilling of the planting holes. Soil samples taken May 10th revealed that the soil moisture content was approximately 15%. Four classes of northern red oak seedlings were established at the site.

> **Class 1**: 1-0 seedlings: No shoot or root pruning. Seedlings were planted in holes 20 cm in diameter and 30 cm in depth formed by a post-hole digger.
>
> **Class 2**: 1-0 seedlings: No shoot pruning, but taproot pruned to a length of 20 cm and the lateral roots pruned to 10 to 15 cm in length. These seedlings were hand planted in slits formed by a KBC planting bar.
>
> **Class 3**: 2-0 seedlings: Shoot pruned to a length of 25 cm above the root-collar, but no root pruning. The seedlings were planted in holes 20 cm in diameter and 30 cm in depth formed by a post-hole digger.
>
> **Class 4**: 2-0 seedlings: Shoot pruned to a length of 25 cm above the root-collar. The taproot was pruned to a length of 20 cm and lateral roots pruned to 10 to 15 cm in length. The seedlings were planted in slits formed by a KBC planting bar.

Morphological characteristics of 1-0 and 2-0 seedlings were similar and the effect of seedling age was assumed to be secondary to the treatments applied in the study (Table 1).

The following measurements were made on all seedlings that were obtained from the nursery.

1. The height from the root-collar to the terminal bud (cm).
2. The root-collar diameter (nearest 0.02 mm).
3. The number of growth flushes.
4. The number of first-order lateral roots (FOLR) with a diameter greater than or equal to 1 mm. For seedlings that were root-pruned, the number of FOLR before and after the root-pruning treatment was recorded to determine how many FOLR were removed by the root-pruning treatment.
5. Seedling stem volume (cm^3) was calculated as 1/3 (¶ r^2 H) where r=radius of the root-collar and H=seedling height. Our previous studies indicate that there is a high correlation between this biomass index and stem dry weights (R^2 values from 0.77-0.98 with a mean of 0.88).

Table 1.—Initial morphological characteristics of seedlings used in the study (n = 80 per seedling class)

	Seedling type			
	Class 1 1-0	**Class 2 1-0**	**Class 3 2-0**	**Class 4 2-0**
Morphological Characteristic	**No sht pr No rt pr**	**No sht pr Rt pr**	**Sht pr No rt pr**	**Sht pr Rt pr**
Height (cm)	56.8 ab*	60.1 a	55.3 b	56.9 ab
Root collar diameter (mm)	9.35 a	9.37 a	8.54 b	9.20 a
Number of flushes	3.34 b	3.30 b	4.45 a	4.46 a
Stem volume (cm^3)	14.44 a	15.30 a	10.83 b	13.21 a
Number of FOLR before pruning	16.7 a	14.1 b	16.2 a	15.5 ab
Number of FOLR after pruning	--	10.1 a	--	11.4 a
Number of FOLR removed by pruning	--	4.0 a	--	4.1 a

*Means in the same row followed by the same letter are not significantly different at P=.05 using Duncan's Multiple Range Test.

The study design was a randomized complete block design with four seedlings (1 of each type of seedling) included in each of the 80 blocks giving a total of 320 seedlings in the study. Duncan's Multiple Range Test was used to determine if differences existed in initial seedling morphological characteristics of seedling classes (SAS Institute, 1985). Seedling height was measured at the end of the first growing season. Net height growth was the seedling height (end of the growing season) minus the initial height. For shoot-pruned seedlings, net height growth was the height at the end of the first growing season minus 25 cm. Analysis of variance tests were conducted to determine if first-year net height growth differed among seedling types. Duncan's Multiple Range Test was used to separate mean net height growth by seedling class (SAS Institute, 1985). Pearson Correlation Coefficients were calculated for the relationship between first-year net height growth and initial morphological characteristics of the seedlings.

At two week intervals from May to October, gravimetric soil moisture was determined from soil cores obtained at depths of 0-15 cm and 15-30 cm from 5 random locations in the field (Figure 1). Rainfall data was obtained from the Purdue Agronomy farm located approximately 3 miles from the planting site (Figure 1). The lines showing the soil moisture tension corresponding to a given gravimetric soil water content were developed for the Ap horizon of a Fincastle soil at the Purdue Agronomy Farm (Wiersma, 1984).

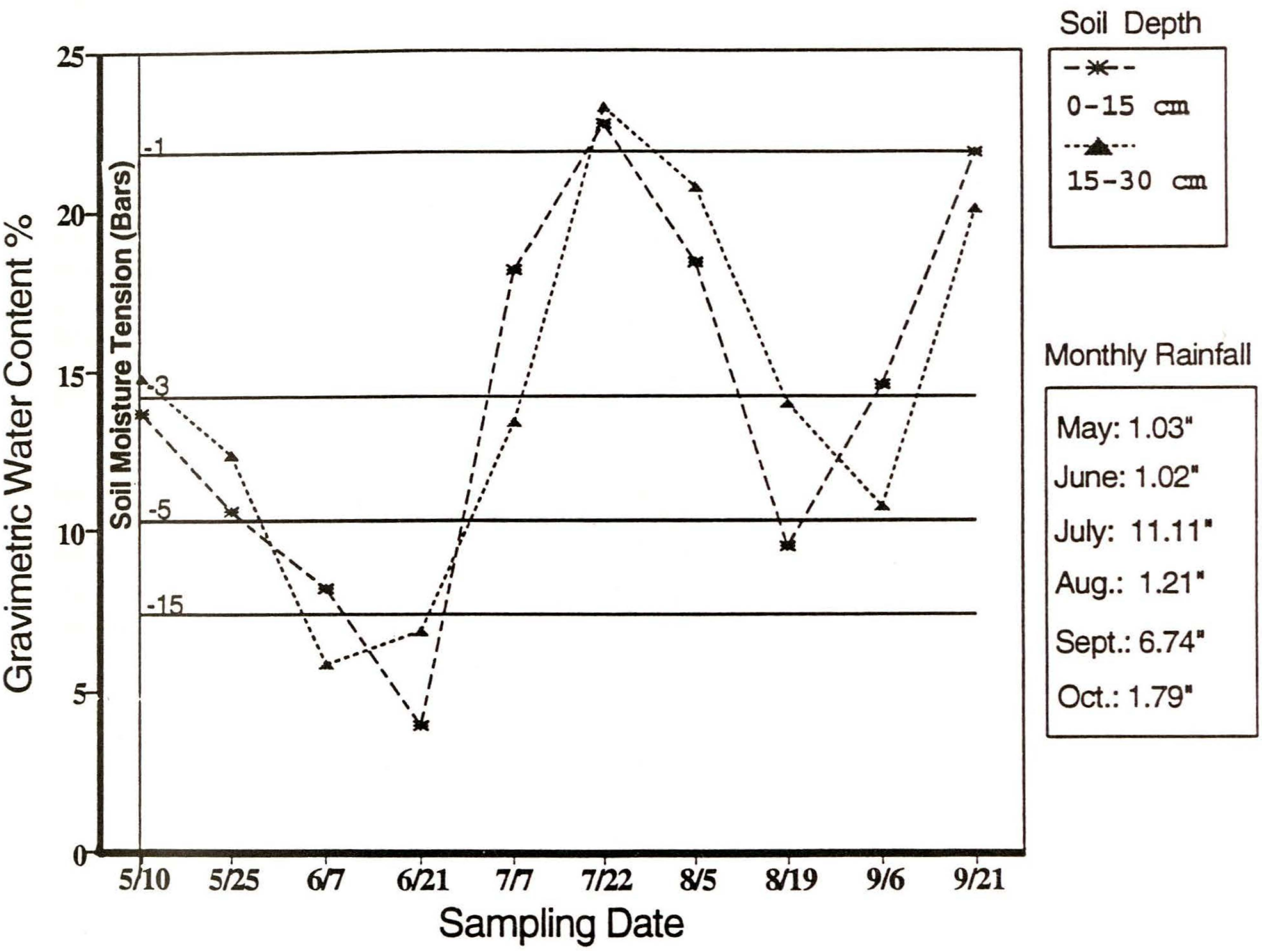


Figure 1.—Gravimetric soil water contents at 0-15 cm and 15-30 cm depths taken every two weeks. Monthly rainfall data is listed to the right of the graph.

At the conclusion of the first-growing season all surviving seedlings were measured to determine net height growth for the first season. Net height growth was defined as the living height of the seedling minus the initial height when planted. In the middle of October, 1992, five blocks of seedlings (20 total, 5 from each treatment) were randomly selected and excavated by hand. Seedlings were lifted by removing a soil volume approximately 80 cm in radius and 60 cm in depth surrounding each seedling. The root system of each seedling was carefully freed from the soil mass and washed free of soil. The following measurements were made on each root system:

1. The number of FOLR greater than 1 mm.
2. The total FOLR length (cm).
3. The total FOLR volume (cm^3) was calculated by determining the volume of each FOLR using the equaltion of a cone and summing these values to obtain the total seedling FOLR volume.
4. The change in the number of roots was calculated as the difference between the number of FOLR at the time the seedling was excavated and the number of FOLR when planted. For root-pruned seedlings this number was obtained by subtracting the number of FOLR found upon excavation minus the number present after the root-pruning treatment was applied.

RESULTS

Initial morphological characteristics for all four classes of seedlings are listed in Table 1. The mean root-collar diameter and the calculated mean stem volume of seedlings assigned to the shoot-pruned class (class 3) were significantly less than the average root-collar diameter and mean stem volume of seedlings in the three other classes. The average initial height of the shoot-pruned seedlings (class 3) was also statistically less than the average height of the root-pruned seedlings (class 2). The mean number of FOLR varied from a low of 14.1 to a high of 16.7 roots. For seedlings that were root-pruned before planting (classes 2 and 4), the root pruning treatment removed an average of 4 FOLR and 4.1 FOLR, respectively (Table 1).

Mortality was extremely low and was limited to 4 root-pruned seedlings (class 2). The overall seedling survival was 99%. First-year net heightgrowth (living height minus initial height when planted) did differ significantly among seedling types. Shoot-pruned seedlings (classes 3 and 4), whether or not they where root-pruned, averaged 2.8 cm of net height growth. Non shoot-pruned, non root-pruned seedlings (class 1) had a net dieback of -3.2 cm and root-pruned seedlings (class 2) had a net dieback of -7.9 cm (Table 2).

Table 2.—First year net height growth (cm) for the 4 types of seedlings used in the study

Seedling type			
Class 1	**Class 2**	**Class 3**	**Class 4**
1-0 No shoot pr No root pr	1-0 No shoot pr Root pr	2-0 Shoot pr No root pr	2-0 Shoot pr Root pr
-3.2 b*	-7.9 b	2.8 a	2.8 a

*Means followed by the same letter did not differ significantly from each other at P=.05 using Duncan's Multiple Range Test.

Significant correlations existed between seedling morphological characteristics at the time of planting and first-year net height growth (Table 3). Seedlings that were not shoot-pruned (classes 1 and 2) exhibited negative correlations between initial seedling height, the number of seedling flushes and net height growth. Root-pruned seedlings (class 2) exhibited a negative correlation between net height growth and seedling stem volume. Shoot-pruning completely changed the relationships observed for non shoot-pruned seedlings. Shoot-pruned seedlings (classes 3 and 4), regardless of the root-pruning treatment, exhibited positive correlations between net height growth and root-collar diameter, stem volume, and the number of FOLR before root-pruning. Shoot and root-pruned seedlings (class 4) also exhibited positive correlations between height growth and the number of seedling flushes and the number of FOLR remaining following root pruning (Table 3).

Table 3.—Significant correlations between initial seedling morphological characteristics and first-year net height growth for each of the four seedling classes

Class 1: 1-0 Non shoot-pruned, non root-pruned seedlings			
Characteristic	**Prob>F**	**R2**	**r**
Number of flushes	.0229	.0646	-.2542
Initial height	.0048	.0975	-.3122
Class 2: 1-0 Non shoot-pruned, root-pruned seedlings			
Number of flushes	.0277	.0606	-.2462
Initial height	.0001	.2037	-.4513
Class 3: 2-0 Shoot-pruned, non root-pruned			
Root-collar diameter	.0200	.0675	.2598
Number of FOLR	.0177	.0700	.2646
Stem volume	.0041	.1006	.3172
Class 4: 2-0 Shoot-pruned, root-pruned			
Root-collar diameter	.0016	.1206	.3473
Number of flushes	.0235	.0641	.2532
Number of FOLR before root-pruning	.0004	.1473	.3838
Number of FOLR after root-pruning	.0004	.1475	.3841
Stem volume	.0021	.1153	.3396

Seedlings were excavated in October following the first growing season and evaluated for root growth characteristics (Table 4). Seedlings that were not root-pruned (classes 1 and 3) had the greatest FOLR lengths and FOLR volumes. Root-pruned seedlings (classes 2 and 4) lost roots due strictly to the pruning treatment that were not replaced during the course of the first growing season. In addition, seedlings that were not root-pruned but were shoot-pruned (class 3) exhibited significantly lower total FOLR length compared to seedlings that were not root or shoot-pruned (class 1). The differences in root characteristics between seedling classes 1 and 3, and 2 and 4 indicate that shoot-pruning is affecting root growth and/or root regeneration. The differences observed among the root systems of excavated seedlings cannot be completely attributed to root-pruning treatments. Only root pruned seedlings (class 2) exhibited increases in the number of FOLR during the course of the first year. Seedlings in the other classes exhibited decreases in the number of FOLR during the first growing season with seedlings in the shoot-pruned class (class 3) exhibiting the greatest decrease (Table 4).

Table 4.—Root morphological characteristics of seedlings upon excavation following the first growing season (n = 5 per seedling class).

	Seedling type			
	Class 1	**Class 2**	**Class 3**	**Class 4**
Characteristic	**1-0 No sht pr No rt pr**	**1-0 No sht pr Rt pr**	**2-0 Sht pr No rt pr**	**2-0 Sht pr Rt pr**
Number of FOLR before planting	19.4 a*	14.4 a	17.4 a	12.8 a
Number of FOLR after root pruning	--	9.6 a	--	9.8 a
Number of FOLR after excavation	15.2 a	10.6 ab	9.6 ab	6.8 b
Change in number of FOLR	-4.2 bc	+1.0 a	-7.8 d	-3.0 c
Total FOLR length (cm)	248.0 a	94.9 b	124.3 b	53.2 b
Total FOLR volume (cm^3)	4.53 a	1.25 b	2.33 b	0.72 b

*Means in the same row followed by the same letter do not differ significantly from each other at P=.05 using Duncan's Multiple Range Test.

DISCUSSION

Shoot and root-pruning treatments affected both shoot and root growth patterns of northern red oak seedlings. This study reinforces the view that seedling quality is a reflection of a number of morphological characteristics. In quantifying seedling quality, it is the balance between morphological characteristics that must be considered rather than a single root or shoot characteristic. Cultural practices such as shoot or root-pruning that alter morphological characteristics should be expected to alter seedling physiology.

Shoot-pruning reduced the affects of moisture stress even under the rather severe drought conditions which occurred during the seedling establishment phase of this study. Shoot-pruned seedlings demonstrated small positive height growth increments during the first growing season while non shoot-pruned seedlings exhibited stem dieback. The results of this study, though preliminary, support the conclusions of others regarding the long term advantages of shoot-pruning. After five growing seasons, shoot-pruned oak seedlings exhibited as great or greater height growth as unpruned seedlings and perhaps more importantly, were more likely to maintain growth rates that allowed them to compete with other species (Johnson, 1984).

In our study, shoot-pruning influenced seedling growth to a greater degree than root-pruning. Root-pruning had no effect on the net height growth of seedlings that were also shoot-pruned.

Non shoot-pruned seedlings exhibited significantly greater stem dieback than shoot-pruned seedlings. There was a trend for seedlings that were also root-pruned to exhibit greater stem dieback than seedlings that were not root-pruned. Larson (1975) demonstrated that shoot growth of oak decreased as the degree of root-pruning increased. Planting treatments that reduced root biomass had the potential to reduce shoot growth. Our study utilized a very conservative root-pruning treatment, but this was still sufficient to increase stem dieback.

The seedling morphological characteristics associated with increased height growth differed depending on whether the seedlings were shoot-pruned or if the stems were left intact. If seedlings were not shoot-pruned, stem dieback increased with increasing seedling size. Larger seedlings were more prone to extensive shoot dieback than smaller seedlings. This response was completely altered when seedling shoots were clipped. In this case, as seedling size increased, growth of the shoot-pruned seedlings also increased. Growth was positively correlated with seedling characteristics which were indicators of increasing seedling biomass (root-collar diameter, stem volume, and number of FOLR). This is consistent with the work of Johnson (1984) who demonstrated that growth of shoot-pruned oak seedlings increased as initial seedling size increased. In many ways, shoot-pruned northern red oak seedlings appear to behave in a fashion similar to coppiced natural oak regeneration. Growth of small to moderate diameter coppiced oak stems has been shown consistently to increase as initial stump diameter increased (Loftis, 1990, Lowell et al., 1987, Johnson, 1979). Shoot-pruning of oak alters seedling growth responses and has the potential to promote vigorous regrowth from the stem below the pruning cut (Johnson et al., 1984).

The significance of root regeneration and root growth following outplanting is often overlooked, but this study indicates that root growth is altered by planting treatment. All seedlings in this study, with the exception of non shoot-pruned, root-pruned seedlings (class 2), exhibited decreases in the number of FOLR during the course of the first growing season. Northern red oak root regeneration is highly sensitive to both soil temperature and soil water availability (Larson, 1970). Root regeneration is greatest for northern red oak seedlings growing in soils near field capacity (Larson and Whitmore, 1970). As soil moisture decreases, root regeneration potential also decreases and root regeneration ceases altogether at a soil moisture potential of -6 bars (Larson, 1980). Stem dieback also increases as soil water potential decreases. While we have no data on soil temperatures, soil water potentials were below -6 bars within 3 weeks of planting and remained below -6 bars for over 1 month (Figure 1). Figure 2 lists daily rainfall totals for the dates from May 1 through November 1, 1992. During the month of June, soil gravimetric water contents in the top 15 cm of soil dropped to below 4% which corresponds to severe moisture stress on this soil. These levels of soil moisture potential would prevent root regeneration and also increase seedling dieback.

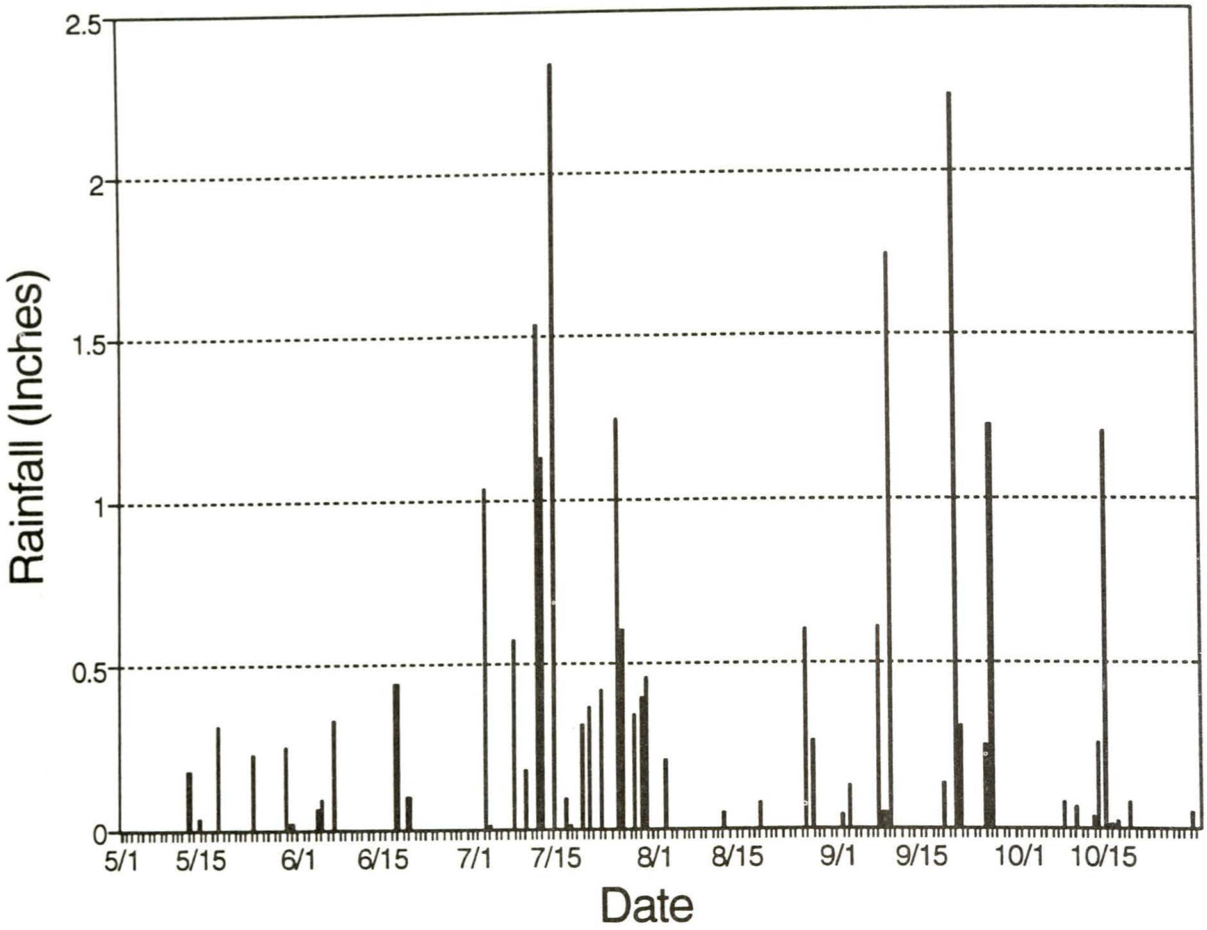


Figure 2.—Daily rainfall amounts for the period of May 1 through November 1, 1992.

Root-pruned seedlings were expected to have lower numbers of FOLR, lower total FOLR length, and lower FOLR volume unless the root-pruning treatment stimulated a proliferation of new root growth. The environmental conditions that limited water availability during the first growing season clearly were not favorable for new root initiation or root growth. Shoot pruning also appeared to influence root growth. We expected seedlings without root-pruning treatments to have the same root characteristics regardless of the shoot-pruning treatment. Instead, shoot-pruned seedlings had lower total FOLR lengths and FOLR volumes. Clearly, shoot-pruning affected root growth of the seedlings. Johnson et al. (1984) also found that shoot-pruning treatments had the potential to reduce root growth of oak seedlings. Farmer (1975) found that root regeneration of oak was dependent on growth regulators produced in intact stems of seedlings. Shoot-pruning treatments could reduce these levels of plant growth regulators and could have an inhibitory effect on root regeneration. In shoot-pruned seedlings, root regeneration may be limited until sprouts from the cut seedling develop. Visual observations in our study revealed that many shoot-pruned seedlings did not develop new shoot growth until soil moisture became favorable in July. Delays in leaf initiation may have reduced root growth and root regeneration.

CONCLUSIONS

Cultural treatments that alter the root-to-shoot ratio of seedlings may alter seedling physiology and responses to environmental stresses. It appears that seedlings with moderate biomass may exhibit less dieback than large (greater than 70 cm in height) seedlings during periods of low rainfall or on drought-prone planting sites. Soil water deficits that occurred during this study probably created relatively high levels of plant moisture stress. Under these conditions, shoot-pruned seedlings exhibited moderate, but positive shoot growth. Non shoot-pruned seedlings in contrast exhibited stem dieback and dieback was increased if the seedlings were also root-pruned. Larger seedlings generally exhibited greater regrowth than smaller seedlings if a shoot-pruning treatment was applied. In contrast, large non shoot-pruned seedlings usually had more stem dieback than smaller seedlings. Shoot-pruning reduced seedling biomass and larger seedlings exhibited greater growth than smaller seedlings. Shoot-pruning may be a method for seedlings with large biomass reserves to realize the potential growth advantage over small seedlings. There is a potential disadvantage to shoot-pruning. It appears that shoot-pruning treatments tend to reduce seedling root growth and root regeneration.

ACKNOWLEDGEMENTS

We would like to thank the State of Indiana and Don Westifer, Manager of the Jasper-Pulaski State Nursery, for providing the seedlings used in this study.

LITERATURE CITED

Cobb, S. W., Miller, A. E., and Zahner, R. 1985. Recurrent shoot flushes in scarlet oak stump sprouts. Forest Sci. 31:725-730.

Farmer, R. E. Jr. 1975. Dormancy and root regeneration of northern red oak. Can. J. For. Res. 5:176-185.

Hilt, D. E. 1977. Introduction of black walnut and northern red oak seedlings in an upland hardwood forest in southeastern Ohio. USDA Forest Service Research Note NE-241.

Homoya, M. A., Abrell, D. B., Aldrich, J. R., and Post, T. W. 1985. The natural regions of Indiana. Proceedings Indiana Academy of Science 94:245-268.

Johnson, P. S. 1979. Shoot elongation of black oak and white oak sprouts. Can. J. For. Res. 9:489-494.

Johnson, P. S. 1984. Responses of planted northern red oak to three overstory treatments. Can. J. For. Res. 14:536-542.

Johnson, P. S., Novinger, S. L., and Mares, W. G. 1984. Root, shoot,and leaf area growth potentials of northern red oak planting stock. Forest Sci. 30:1017-1026.

Larson, M. M. 1970. Root regeneration and early growth of red oak seedlings: influence of soil temperature. Forest Sci. 16:442-446.

Larson, M. M. 1975. Pruning northern red oak seedlings: effects on root regeneration and early growth. Can. J. For. Res. 5:381-386.

Larson, M. M. 1980. Effects of atmospheric humidity and zonal soil water stress on initial growth of planted northern red oak seedlings. Can. J. For. Res. 10:549-554.

Larson, M. M. and Whitmore, F. W. 1970. Moisture stress affects root regeneration and early growth of red oak seedlings. Forest Sci. 16:495-498.

Loftis, D. L. 1979. Northern red oak performs poorly in North Carolina planting. USDA Forest Service Research Note SE-277.

Loftis, D. L. 1990. Predicting post-harvest performance of advance red oak reproduction in the southern Appalachians. Forest Sci. 36:908-916.

Loftis, D. L. and McGee, C. E. 1986. Planted oaks perform poorly in North Carolina and Tennessee. North. J. Appl. For. 8:95-98.

Lowell, K. E., Mitchell, R. J., Johnson, P. S., Garrett, H. E., and Cox, G. S. 1987. Predicting growth and "success" of coppice-regenerated oak stems. Forest Sci. 33:740-749.

SAS Institute, 1985. SAS user's guide: statistics version 5 edition. SAS Institute Inc. Cary, North Carolina. 956 pp.

Wiersma, D. 1984. Soil water characteristic data for some Indiana soil profiles. Purdue University Station Bulletin No. 452. 153 pp.

Performance of Hardwoods Planted With Autumn Olive After Removing Prior Cover

Felix Ponder, Jr.[1]

ABSTRACT.—White ash, white oak, and black walnut were planted with and without autumn olive on a site previously occupied by a 10-year-old stand of autumn olive. Seven years later, height, diameter, and foliar nitrogen were significantly greater in plots with autumn olive than in plots without autumn olive. White oak in plots previously occupied by autumn olive were larger in diameter but shorter than white oak in plots previously inhabited by shrubs and scattered hardwoods. Prior cover of autumn olive apparently did not increase growth more than prior cover of shrubs and scattered hardwoods.

Plantings of hardwoods on old fields rarely succeed. Research suggests that growing conditions for many commercial hardwoods are improved when brushy vegetation is allowed to inhabit old fields for several years before the desired tree species are planted (Carmean *et al.* 1976). Among the more easily established woody plants are those capable of fixing nitrogen such as black locust (*Robinia pseudoacacia* L.), alder (*Alnus* spp.), and autumn olive (*Elaeagnus umbellata* Thunb.). Finn (1953) found that yellow poplar (*Liriodendron tulipifera* L.), sweetgum (*Liquidambar styraciflua* L.), black walnut(*Juglans nigra* L.), and red oak (*Quercus rubra* L.) grew rapidly and had high foliar nitrogen levels when grown in association with black locust. Similar results have been reported by Funk *et al.* (1979) for black walnut mixed with autumn olive and for white ash (*Fraxinus americana* L.) planted with European alder (*Alnus glutinosa* L.[Gaertn.] (Plass 1977). In the absence of the nitrogen-fixing species, these planted hardwoods grew poorly in both studies.

Soil nitrogen has also been found to be greater in mixed forest stands containing nitrogen-fixing species (Hansen and Dawson 1982, Ike and Stone 1958). Interplantings of walnut with black locust and autumn olive had the highest total soil nitrogen concentrations in the top 30 cm of soil, followed by European alder, lespedeza clover (*Lespedeza striata* [Thunb.] Hook & Arn.), and control plots (Friedrich and Dawson 1984).

Soil nitrogen can be extremely variable and ephemeral. It is not known how long the accumulated nitrogen remains in the soil after nitrogen-fixing plants no longer occupy the site. The main objective of this study was to compare the performance of white oak (*Q. alba* L.) planted with and without autumn olive both on an old field previously occupied by autumn olive and on a field with other prior cover. The growth of planted black walnut and white ash with and without autumn olive after the initial stand of autumn olive was removed is also described.

METHODS AND MATERIALS

Site and Site Preparation

The study was established on two bottomland fields on the Kaskaskia Experimental Forest in Hardin County, Illinois; one had been planted to black walnut (Goolsby tract) and the other

---

[1] Supervisory Research Soil Scientist, USDA Forest Service, North Central Forest Experiment Station, Jefferson City, Missouri 65102.

(Rendleman tract) had been planted to black walnut and autumn olive. Both 10-year-old plantings failed because of the poor survival of the black walnut. The few trees that remained were poorly formed and had grown very little. Walnut trees at the Rendleman tract were overtopped by autumn olive for a number of years. The shade provided by the autumn olive prevented establishment and survival of most woody and herbaceous volunteer plants there. Grasses, shrubs, and scattered naturally seeded hardwoods, including cottonwood (*Populus* spp.), sycamore (*Platanus occidentalis* L.), and sweetgum (*Liquidambar styraciflua* L.), made up the ground cover at the Goolsby tract.

Soils on the Goolsby and Rendleman tract are primarily of the Wakeland series (fine-silty, mixed, mesic, Aeric Fluvaquents). Most of the Goolsby tract has slopes near 3 to 5%. The silt clay loam soil there is moderately well drained to somewhat poorly drained and 1.5 to 2.2 m deep. Soils on the Rendleman tract have depths similar to those on the Goolsby tract and are nearly level and somewhat poorly drained.

To prepare the sites, existing trees and autumn olives were removed using a small tractor with a bulldozer. The overall disturbance caused by the clearing was slight. Many of the branches and roots were removed from the site by hand. The sites were disked several times after clearing. All site preparation was done in the summer and fall of 1982.

Study Design and Measurements

One-year-old nursery-grown seedlings were planted on both tracts in the spring of 1983. Rows were 3.1 m apart, and seedlings in the rows were 2.4 m apart. In the mixed treatment, autumn olive seedlings were interplanted within the rows at a spacing of 1.2 m from tree seedlings. Each tree seedling in the mixture was flanked by two autumn olives. White ash, white oak, and black walnut were planted with and without autumn olive at the Rendleman tract, and white oak only was planted with and without autumn olive at the Goolsby tract. The study was laid out as a completely randomized design. Each treatment was replicated 4 times. Each replicate contained 60 tree seedlings. Dead and missing seedlings were replaced in the spring of 1984. Autumn olive outgrew many of the oaks, and it was cut to near ground level in 1985 at the Goolsby tract and to a height of 1 m in 1988 in oak plots at both sites.

Simazine and glyphosate were applied in a 0.5-m band, on both sides of the seedling rows annually from 1983 through 1986. Simazine was applied at 4.4 kg/ha, usually in early March, and glyphosate (5.4 l/ha) was applied before the first of May.

Height and diameter (30.5 cm above the ground) have been recorded on 32 interior trees/replicate each fall since 1983. Leaf and soil (0 to 15.2 cm) samples were collected in mid-June of 1989 for nutrient analyses. Data were subjected to an analysis of variance; differences were considered statistically significant at the 0.05 level according to Duncan's multiple range test.

RESULTS

Survival

Survival declined at both sites between the years of 1985 and 1989, with the greatest decline at the Goolsby tract (Table 1). Plots with autumn olive at the Goolsby tract had 25% fewer trees in 1989 than 4 years earlier, while plots without autumn olive declined by only 12%.

Table 1.—Percent survival of hardwoods planted with and without autumn olive at two locations

	Rendleman tract						Goolsby tract	
	White ash		Black walnut		White oak		White oak	
Year	Without	With	Without	With	Without	With	Without	With
1985	96	100	100	100	98	93	91	100
1989	94	98	89	91	96	89	79	75

Over the same period, survival of oaks on the Rendleman tract declined by only 4 and 2% with and without autumn olive, respectively. The survival of white ash and black walnut was only slightly higher with autumn olive than without.

Height and Diameter

Seven years after outplanting, trees planted with autumn olive were taller and larger in diameter than trees planted in plots without autumn olive (Tables 2 and 3). Height enhancement attributed to autumn olive was not apparent in all trees in the same year. Differences in black walnut height began to be noticeable by year 5, but differences were not significant (a = 0.05) until year six. Height differences between treatments in white ash were not apparent until year six and were significant by year seven. Overall, white ash and black walnut planted with autumn olive were 0.62 and 0.78 m taller, respectively, than trees planted without autumn olive. Trees planted with autumn olive were also larger in diameter than trees planted without autumn olive; however, differences between the two treatments were not significant until year seven for white ash and year six for black walnut.

Table 2.—Height and diameter of white ash and black walnut outplanted with and without autumn olive at the Rendleman tract after years 4 through 7

	Year[a]			
Treatment	4	5	6	7
		Height (m)		
Ash alone	2.86a	3.31a	3.74a	3.42a
Ash/autumn olive	2.98a	3.30a	4.00a	4.44b
Walnut alone	0.58a	0.65a	0.64a	0.78a
Walnut/autumn olive	0.73a	0.87a	1.04b	1.40b
		Diameter (cm)		
Ash alone	33.15a	41.10a	43.74a	44.80a
Ash/autumn olive	36.15a	42.40a	44.65a	48.40b
Walnut alone	9.35a	10.00a	8.60a	11.30a
Walnut/autumn olive	11.50a	12.35a	11.70b	14.75b

[a]Means within the same column and species followed by the same letter are not significantly different at the 0.05 level.

Table 3.—Height and diameter of white oak outplanted at two locations, with and without autumn olive, after years 4 through 7

Location	Autumn olive	Year[a] 4	5	6	7
			Height (m)		
Rendleman	Without	0.60a	0.95a	1.20a	1.77a
Rendleman	With	0.79a	1.40b	1.84b	2.39b
Goolsby	Without	0.71a	0.90a	1.69a	2.05a
Goolsby	With	1.10b	1.62b	2.25b	2.93b
			Between locations		
Rendleman		69.25a	117.50a	151.50a	207. 75a
Goolsby		91.33a	130.13a	205.33b	257.00a
			Diameter (cm)		
Rendleman	Without	9.55a	13.10a	19.45a	28.15a
Rendleman	With	11.38b	18.55b	25.90a	35.70b
Goolsby	Without	12.90a	14.90a	19.60a	25.61a
Goolsby	With	16.52a	21.63b	22.94a	28.27a
			Between locations		
Rendleman		10.45a	15.60a	22.68a	31.92a
Goolsby		14.95b	17.91a	20.82a	27.02a

[a] Means within the same column for a parameter followed by the same letter are not significantly different at the 0.05 level.

White oak planted with autumn olive averaged 30 and 25% taller than white oak planted alone at the Goolsby and Rendleman tracts, respectively (Table 3). Height differences were not significant until year 4 at the Goolsby tract and year 5 at the Rendleman tract. Trees planted with autumn olive also had larger diameters than white oak planted alone (Table 3). However, at the Goolsby tract, the difference between diameters for the two treatments was significant only for year 5. By year 7, the trees at the Goolsby tract were taller and smaller in diameter than trees at the Rendleman tract, but the difference was not significant. Height and diameter differences between locations were significant (a = 0.05) in year 6 and year 4, respectively.

Nutrient Elements

Soil nitrogen in all plots ranged from 0.10 to 0.13% (Tables 4 and 5). Differences between soil nutrients among treatments were not significant in ash and walnut plots. There were no significant differences between treatments for oak plots at the Goolsby tract, but there were differences at the Rendleman tract (Table 5). Potassium, calcium, and magnesium were higher at the Goolsby tract than at the Rendleman tract.

Foliar nitrogen was higher in leaves from trees planted with autumn olive than in leaves from trees planted alone (Table 4). With autumn olive, leaf nitrogen averaged 2.6 and 2.8% for white ash and black walnut, respectively, compared to 1.4 and 1.7%, respectively, without autumn olive. Both foliar calcium and magnesium were higher in the walnut-alone treatment than in the walnut/autumn olive mixture; the opposite was true for magnesium in ash leaves.

Table 4.—Concentration of nutrient elements in soil and leaves of trees in white ash and black walnut plots.

Treatment	Nutrient element[a]					
	N	P	K	Ca	Mg	Mn
	(%)	- - - - - - - - - (μg/g of sample) - - - - - - - - -				
Soil						
Ash alone	0.10a*	48a	71a	344a	41a	381a
Ash/autumn olive	0.11a	58a	72a	293a	35a	383a
Walnut alone	0.12a	58a	88a	363a	42a	382a
Walnut/autumn olive	0.10a	45a	65a	409a	36a	334a
Leaves						
Ash alone	1.4a	1,185a	10,823a	8,592a	1,385a	159a
Ash/autumn olive	2.6b	1,314a	9,398a	9,386a	2,069b	170a
Walnut alone	1.7a	1,507a	9,604a	20,853a	3,129a	401a
Walnut/autumn olive	2.8b	1,313a	9,195a	15,085b	2,494b	470a

[a] Key to symbols: N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; Mn = manganese.

*Means within the same column and species followed by the same letter are not significantly different at the 0.05 level.

Nitrogen levels were also higher in leaves from white oaks planted with autumn olive than from white oaks planted alone at both locations (Table 5). Both magnesium and manganese were higher in the leaves of white oak mixed with autumn olive than in white oak alone at the Goolsby tract, but magnesium was higher in the white oak-only plot at the Rendleman tract. Nitrogen and manganese levels were higher in oak leaves at the Rendleman tract than at the Goolsby tract.

DISCUSSION

Survival was good for all three tree species at both sites; however, both ash and walnut had considerable dieback resulting in multiple stems in some instances. In such cases, had all of the biomass been in one stem, measured growth might have been more. Compared to walnut and ash, fewer oaks died back, but their overall height was intermediate between the other two species.

Neither site has soil recommended for good hardwood growth, especially black walnut (Losche 1973). Soils have sufficent depth, but they are somewhat poorly drained; well drained soil is recommended. The mean height (1.4 m) of walnut was significantly taller in the autumn olive/walnut mixture than in the walnut-only plots, but this height was much less than the 2.7 m reported for another 7-year-old walnut (Van Sambeek *et al.* 1985) or the 6.8 to 5.1 m reported for 9-year-old walnut (Funk *et al.* 1979)

Finn (1953) reported that white oak planted with black locust had 0.5% more nitrogen than white oak planted alone. In the present study, the oak, ash, and walnut planted with autumn olive averaged nearly 0.2, 0.5, and 0.4%, respectively, more leaf nitrogen than trees planted alone.

Table 5.—Concentration of nutrient elements in soil and oak leaves at two locations

		Nutrient element[a]					
Location	**Autumn olive**	**N**	**P**	**K**	**Ca**	**Mg**	**M**
		(%)	- - - - - - - -	- (μg/g	of sample) -	- - - - - - -	
Soil							
Rendleman	Without	0.12a*	48a	88a	571a	64a	437a
Rendleman	With	0.10a	48a	56a	343b	36b	399a
Goolsby	Without	0.13a	32a	116a	1912a	126a	376a
Goolsby	With	0.13a	33a	103a	2143a	130a	353a
				Between locations			
Rendleman		0.11a	48a	72a	457a	50a	418a
Goolsby		0.13a	33a	110b	2028b	128b	365a
Leaves							
Rendleman	Without	2.00a	1286a	6138a	14570a	1071a	584a
Rendleman	With	3.05b	1538a	8015a	13489a	1640b	511a
Goolsby	Without	1.73a	1414a	6411a	15828a	1225a	174a
Goolsby	With	3.10b	1506a	7064a	14323a	1701b	282b
				Between locations			
Rendleman		2.78a	1412a	7077a	14030a	1356a	548a
Goolsby		2.42b	1460a	6738a	15076a	1463a	228b

[a] Key to symbols: N = nitrogen; P = phosphorus; K = potassium: Ca = calcium: Mg = magnesium: Mn = manganese.

*Means for a location or between locations followed by the same letter are not significantly different at the 0.05 level.

Trees at the Goolsby tract were taller but smaller in diameter than trees at the Rendleman tract. The smaller diameter of the trees can probably be attributed to the crowding caused by the autumn olive, which grew faster at the Goolsby tract than at the Rendleman tract. The autumn olive outgrew many of the oaks by as much as 0.8 m in 1985, and by 0.5 m in 1988, after being cut back to near ground level. The crowding probably created an effect described as "fur coat," which tends to increase height growth at the expense of diameter growth (Ivanova 1953). Ivanova (1953) reported that young oaks grew well in protected, lateral shade conditions provided by accessory species similar to the environment created by autumn olive (Funk *et al.* 1979). The favorable effect of the "fur coat" ceases when autumn olive outgrows the oak and interferes with its height growth.

Trees and autumn olive in this study were planted at a closer spacing than those reported for several other mixed plantings (Table 6). Therefore, trees in closer spaced plantings might respond sooner to the autumn olive than trees in more widely spaced plantings. However, growth differences attributed to autumn olive were not apparent until year 4, which is within the usual range of years reported for other studies (Table 6).

Table 6.—Initial black walnut growth response to interplanted species and spacing

Source	Between walnuts in the row	Between rows	Between inter-planted species	Years before response
	- - - - - - - - - - -	Meter - - - - - - - - - - -		Number
This study	2.4	3.1	1.2	4 to 5
Schlesinger and Williams 1984	4.9	3.7	2.5	4 to 5
	3.4	3.4	1.7	4 to 5
Van Sambeek et al. 1985	4.2	3.0	3.3	5 to 6

Friedrich and Dawson (1984) reported that soil nitrogen concentration in more closely spaced (3.7 x 4.9 m) plots of autumn olive and black walnut was higher than in wider spaced (3.7 x 9.8 m) plots, but the size of the walnut was not closely correlated with the accrued soil nitrogen in mixed plots. Walnut size was generally greater in mixed plots at the wider 3.7 x 9.8 m spacing. This suggests that soil nitrogen accounts for only a part of the growth difference attributed to interplanted nitrogen-fixing species. Other factors such as reduced weed competition, wind protection, lower air and soil temperatures, and higher canopy humidity might be associated with the better growth of trees in mixed plots.

Interplanting autumn olive has significantly increased the growth of associated hardwood in plantings on both sites and for all three species in this study. However, results from this study do not provide evidence that a site previously occupied by autumn olive is superior to a site previously occupied by scattered hardwoods and shrubs in promoting growth of planted trees.

LITERATURE CITED

Carmean, W. H., F. B. Clark, R. D. Williams, and P. R. Hannah. 1976. Hardwoods planted in old fields favored by prior tree cover. USDA For. Serv. Res. Pap. NC-134. 16 p.

Finn, R.F., 1953. Foliar nitrogen and growth of certain mixed and pure forest plantings. J. For. 51:31-33.

Friedrich, J. M., and J. O. Dawson. 1984. Soil nitrogen concentration and *Juglans nigra* growth in mixed plots with nitrogen-fixing *Alnus*, *Elaeagnus*, *Lespedeza*, and *Robina* species. Can. J. For. Res. 14:864-868.

Funk, D.T., R. C. Schlesinger, and F. Ponder, Jr. 1979. Autumn olive as a nurse plant for black walnut. Bot. Gaz., 140(Suppl.): S110-114.

Hansen, E. A., and J. O. Dawson. 1982. Effect of **Alnus glutinosa** on hybrid populus height growth in short-rotation intensively cultured plantations. For. Sci. 28:49-59.

Ike, A. F., Jr., and E. L. Stone. 1958. Soil nitrogen accumulation under black locust. Soil Sci. Soc. Am. Proc. 22:346-349.

Ivanova, N. E. 1953. Effects of the lateral shading of oak on its height growth. P. 74 - 91. in Young oak stands on dark-gray loamy soils in upland oak woods in the forest steppe. (Translated from Russian by N. Kaner). Academy of Sciences of the USSR Forest Institute.

Losche, C. K. 1973. Black walnut growth better on deep, well-drained bottomland sites. USDA For. Ser. Res. Note NC-154. 3 p.

Plass, W. T. 1977. Growth and survival of hardwoods and pine interplanted with European alder. USDA Res. Pap. NE-376. 10 p.

Schlesinger, R. C., and R. D. Williams. 1984. Growth response of black walnut to interplanted trees. For. Ecol. and Manage. 9:235-243.

Van Sambeek, J. W, R. C. Schlesinger, F. Ponder, Jr., and W. J. Rietveld. 1985. Actinorhizal species as nurse crops for black walnut. P. 257-263. in Proc. Fifth Cent. Hardwood For. Conf. Urbana-Champaign, IL.

AUTHOR AND ACKNOWLEDGMENT

The author is Project Leader of the North Central Forest Experiment Station's Long-Term Site Productivity Research Work Unit located at Jefferson City, Missouri on the campus of Lincoln University. The author thanks Elbert Rendleman (retired), Darrell Alley, Judith Larsen, and Valerie Roe for assistance in the field installation and data collection of this study, and Richard Schlesinger and George Rink, who reviewed and provided helpful comments on an earlier draft of this paper.

Interplanting Woody Nurse Crops Promotes Differential Growth of Black Walnut Saplings

J. O. Dawson and J. W. Van Sambeek[1]

Abstract: Interplanting black walnut (*Juglans nigra*) with four different nitrogen fixing, woody nurse crops (*Alnus glutinosa, Elaeagnus umbellata, E. angustifolia* or *Caragana arborescens*) increased annual walnut height and stem diameter (dbh) growth overall by as much as 50% and doubled or tripled crown volume compared to all-walnut check plots during a 14-year period after plantation establishment. Walnut interplanted with non-nitrogen fixing, woody nurse crops (*Lonicera maackii, Acer ginnala,* or *Pinus sylvestris*) in a companion experiment of 12 years duration did not grow significantly more than walnut in check plots. Experimental plantings were established adjacent to one another in 1978 and 1980 in central Illinois. A split-split plot design divided by replications and sites was employed in both experiments with equal numbers of walnut and the interplanted nurse species intermixed alternately at a 3 x 3-m overall spacing in plots. Walnut trees at a floodplain site had less mortality and significantly greater growth than walnut trees at an upland site. Results indicate that nitrogen fixing nurse crops can be superior to non-nitrogen fixing nurse crops in promoting walnut growth, specifically confirming the possible importance of nitrogen fixation relative to other nurse crop benefits in promoting walnut growth on sites considered good to marginal for black walnut.

INTRODUCTION

The wood of black walnut (*Juglans nigra* L.) is highly esteemed for its rich brown color and pleasing luster. Black walnut trees also produce edible nut meats and shells used as an abrasive in industrial processes. There is a strong and increasing interest in planting black walnut seedlings both within and ouside of its native range. Black walnut requires deep, well-drained, fertile soils with high moisture availabiliy for optimal commercial growth (Losche 1973, Ponder 1980). Wind protection also significantlty improves growth of black walnut seedlings (Heiligmann and Schneider 1975). It follows that black walnut growth does in fact vary greatly with soil properties, associated vegetation, and topography together with climate, cultural practises, insects, and diseases (Williams 1990).

One promising technique for improving walnut growth in plantations is the use of woody nurse crops. Nurse crops are plants intended to foster another, generally more important crop (Ford-Robertson 1971). Nurse crops can affect walnut growth by altering soil properties, microclimatic conditions, associated vegetation, and interactions with disease organisms and insects (Schlesinger and Williams 1984). Nitrogen-fixing nurse crops have been reported to improve growth of black walnut on a range of sites in the midwestern United States and the benefits of interplanting seem to be inversely related to site productivity for walnut alone (Schlesinger and Williams 1984). Nitrogen fixed symbiotically by bacteria in root nodules of nitrogen-fixing plants probably becomes available to associated plants when soil is enriched by inputs of nitrogen rich litter and sloughed root tissue from the nitrogen-fixing plant (Friedrich and Dawson 1984). Non-nitrogen fixing conifers (von Althen and Nolan 1988) and woody angiosperms have also improved walnut growth through interplanting (von Althen 1989).

---

[1] Department of Forestry, University of Illinois, Urbana, IL 61801 and USDA Forest Service, North Central Forest Experiment Station, Carbondale, IL 62901-4630.

The mechanisms responsible for increased walnut growth in these complex, mixed silvicultural systems are not precisely known. Particularly lacking is site-specific information on the importance of nitrogen-fixation by a woody nurse crop relative to wind-protection and other interplanting benefits afforded equally by non-nitrogen fixing nurse crops. We address this question by providing information on walnut growth at two contrasting locations in central Illinois in replicated interplantings with nitrogen-fixing black alder (*Alnus glutinosa* [L.] Gaertn.), autumn olive (*Elaeagnus umbellata* Thunb.), Russian olive (*Elaeagnus angustifolia* L.), or Siberian pea shrub (*Caragana arborescens* Lam.), as well as with non-nitrogen fixing Amur honeysuckle (*Lonicera maackii* Maxim.), Ginnala maple (*Acer ginnala* Maxim.), Scots pine (*Pinus sylvestris* L.), or walnut check plots.

MATERIALS AND METHODS

Black walnut interplantings were established on a bottomland and an upland site in 1978 and 1980 at the Macon County Conservation District south of Decatur, Illinois (89o 01' west, 39o 50' north). The bottomland plantation was established on an agricultural field located in the Sangamon River floodplain. The soil is of the Lawson silt loam series and is a fine silty mixed mesic Cumulic Hapludoll (Carroll County Soil Survey 1975). This Mollisol has somehat poor internal drainage, having a silt loam surface layer and a silt clay loam subsoil. Because of the poor internal drainage these soils have been considered questionable for walnut (Losche *et al.* 1980), but otherwise are fertile with a high available water capacity. In the summer of 1991, understory vegetation on the bottomland site consisted primarily of perennial forbs with tall fescue invading from roadbanks along two sides.

The upland plantation was established in a hayfield on an upland flat. The upland soil is of the Birkbeck silt loam series, a fine silty mixed mesic Typic Hapludalfs (Champaign County Soil Survey 1982). This Alfisol is somewhat poorly to moderately well drained, having a silt loam surface layer and a silty clay loam subsoil, and have been considered suitable for supporting walnut growth (Losche et al. 1980). In the summer of 1991, understory vegetation on the upland site consisted of either a tall fescue or bromegrass sod with few annual or perennial forbs.

A split-split plot experimental design was used with treatment plots split by site and by replication. There were two sites and four plot replications per treatment. Treatments in the first experiment established in 1978 were mixed plantings of black alder, autumn olive, Russian olive, or Siberian pea shrub with black walnut plus a control treatment in which walnut trees were planted as the nurse-crop. The 1980 experiment was located adjacent to the 1978 experimental planting and consisted of Amur honeysuckle, Ginnala maple, or Scots pine interplanted with walnut plus a control treatment in which walnut trees were planted in the same manner as the nurse-crops. Each plot was 18 x 21 m and was planted with one-year-old nursery-grown walnuts spaced 6 m apart within rows and 3 m between rows using staggered rows so that walnuts were 4.2 m equidistant in a diamond configuration. Nurse-crop seedlings were planted between the walnuts in each row to achieve a 3 x 3 m overall spacing in a 1:1 ratio of walnut to nurse-crop seedlings. In the walnut check plots additional walnut seedlings were planted in place of the nurse-crop trees and were treated as nurse trees in statistical analyses.

Black alder, autumn olive, and Russian olive are actinorhizal (nodulated by the actinomycete *Frankia*), nitrogen-fixing host plants. Siberian pea shrub is a woody legume nodulated by rhizobial soil bacteria. The non-nitrogen fixing species were selected to approximate the form and growth rate of autumn olive or to provide year-around shading and wind protection.

Weeds were controlled for the first three years by directed spraying of a mixture of glyphosate (2.5 l active ingredient per ha) and simazine (2.2 kg active ingredient per ha) in 1.5-m-diameter circles around each seedling. Weeds around black alder trees were controlled by placing 1.2-m-wide black plastic squares around each tree due to the sensitivity of this species to herbicide. The plantations were mowed annually in July and again each autumn.

At the end of the 1991 growing season, total height and stem diameter at breast height (1.3 m) for the 10 interior walnut and the associated 10 interior interplanted trees, if they possessed a predominant or single main stem, were measured in each treatment plot. This allowed for a border row around each plot. We also measured the crown diameter along the cardinal directions for the interior 20 trees to provide another growth parameter particularly for the predominantly multistemmed, shrubby interplantings. Missing trees were tallied for estimating survival of woody plantings. Individual crown volumes were estimated as ellipsoids of revolution about the tree height or $4/3\ \pi$ (height/2) (mean crown radius^2).

Data for mean walnut height and stem diameter at breast height (dbh) annual growth rates were subjected to variance analyses together with means for estimated crown volume. The mean squares for the replication by site interaction were used as an error term in order to adjust for sampling error. The 1978 and 1980 data were analyzed as separate experiments, both of which employed a split-split plot experimental design. The generalized least-squares method of the Statistical Analysis System (SAS Institute Inc. 1985) was employed in order to adjust for unequal numbers of experimental units due to mortality. Comparisons among treatment and site plot means were made with Duncan's new multiple range test.

RESULTS AND DISCUSSION

Analysis of variance for the 1978 experiment with interplanted nitrogen fixing woody species as treatments indicated that both interplanting treatment and site contributed significantly to overall variation for all walnut growth variables ($P = 0.01$). Treatment by site interaction was significant only in the case of crown volumes, with the relative differences among crown volume means for treatments being much greater on bottomland than on upland sites. Linear correlation coefficients indicate that the experimental model accounted for 93% of the total variation in annual walnut height growth, 98% of the total variation in annual walnut dbh increment, and 93% of the total variation in walnut crown volume. Comparison of treatment and site means indicates that walnut interplanted with nitrogen fixing trees and shrubs grew significantly more than walnut in check plots with additional walnut in place of other interplantings (Table 1). Black alder and Russian olive promoted walnut growth better than autumn olive or Siberian pea shrub in cental Illinois. Walnut growth on the bottomland site was significantly greater than walnut growth on the upland site (Table 2).

Table 1.—Overall differences among interplanting treatments in mean annual height growth, annual dbh increment, and estimated crown volume of walnut trees for the 1978 experiment (14-y-old trees) employing nitrogen fixing interplantings. Whole plot mean values are used to calculate treatment mean differences in the split-split plot design (n=8).

Interplanted species	**Annual ht increment (m)**	**Annual dbh increment (cm)**	**Crown volume (m^3)**
Alder	0.42 a*	0.57 a	35.94 a
Rus. olive	0.36 a	0.56 a	34.77 a
Aut. olive	0.29 b	0.46 b	27.48 a
Pea shrub	0.29 b	0.45 b	28.50 a
Walnut	0.23 b	0.35 c	12.15 b

* Means in a column followed by the same letter are not significantly different (P = 0.05).

Table 2.—Overall differences between upland and bottomland sites in mean annual height growth, annual dbh increment, and estimated crown volume of walnut trees for 1978 experiment (n=20)

Topographic position	**Annual ht increment (m)**	**Annual dbh increment (cm)**	**Crown volume (m^3)**
Upland	0.15 a*	0.15 a	1.88 a
Bottomland	0.48 b	0.80 b	53.66 b

* Means in a column followed by the same letter are not significantly different (P = 0.01).

In the 1980 experiment employing interplanted woody plants of species incapable of nitrogen fixation as treatments, the interplanted species did not contribute significantly to overall variation for any walnut growth variable, whereas site contributed significantly to overall variation of all walnut growth variables (P = 0.01). Linear correlation coefficients indicate that the experimental model accounted for 89% of the total variation in annual walnut height growth, 87% of the total variation in annual walnut dbh increment, and 75% of the total variation in walnut crown volume. Treatment mean comparisons illustrate the similarity among growth-variable means of walnut where trees and shrubs incapable of nitrogen fixation were the interplanting treatments (Table 3). There was a pronounced difference in walnut growth between upland and bottomland sites as in the 1978 experiment (Table 4). There was little difference in mean values for walnut growth in check plots between the 1978 and 1980 experimental plantings (Tables 1 and 3).

Table 3.—Overall differences among interplanting treatments in mean annual height growth, annual dbh increment, and estimated crown volume of walnut trees for the 1980 experiment (12-y-old trees) employing interplantings incapable of nitrogen fixation. Whole plot mean values are used to calculate treatment mean differences in the split-split plot design (n=8).

Interplanted species	Annual ht increment (m)	Annual dbh increment (cm)	Crown volume (m^3)
Scots pine	0.28 a*	0.40 a	12.22 a
Amur maple	0.24 a	0.33 a	11.37 a
Honeysuckle	0.24 a	0.34 a	14.17 a
Walnut	0.24 a	0.36 a	9.02 a

* Means in a column followed by the same letter are not significantly different (P = 0.05).

Table 4.—Overall differences between upland and bottomland sites in mean annual height growth, annual dbh increment, and estimated crown volume of walnut trees for 1980 experiment (n=20)

Topographic position	Annual ht increment (m)	Annual dbh increment (cm)	Crown volume (m^3)
Upland	0.09 a*	0.11 a	0.22 a
Bottomland	0.40 b	0.58 b	23.17 b

* Means in a column followed by the same letter are not significantly different (P = 0.01).

Walnuts interplanted with woody, nitrogen-fixing nurse crops were 30 to 50% taller and had more than twice the mean value for crown volume on a floodplain site than did walnuts interplanted with non-nitrogen fixing woody plants or in pure walnut plantings with walnut substituted for a nurse crop (Table 5). Walnut mortality was low on this bottomland site, but interplanted autumn olive, Russian olive, Siberian pea shrub, and Scots pine, which survive and grow better under drier soil conditions, had high mortality. Mortality of black alder, which characteristically tolerates moist soil conditions, was also high on the bottomland site. Black alder is particularly sensitive to walnut's allelochemical juglone (Rietveld 1983, Rietveld *et al.* 1983).

Walnut survival and growth on the upland site were less than on the bottomland site (Table 6). Height and diameter growth of walnut on the upland site were greatest where walnut trees were interplanted with nitrogen-fixing trees that also possessed large crown volumes, indicative of an ability to afford shelter. Large crown volumes would also indicate a higher capacity to fix nitrogen, since nodular nitrogen fixation is closely related to the amount of host-plant leaf tissue providing

Table 5.—Mean survival percentage and dimensions of 12- to 14-year-old walnut trees and nurse trees interplanted in equal proportions in floodplain plots with 3 x 3-m spacing

Paired species	Survival % (initial no.)	Height (m)	Dbh (cm)	Crown volume (m^3)
Alder	7 (40)	5.95	5.3	23.59
Walnut	00 (40)	7.50	4.5	45.35
Aut. olive	30 (40)	2.64	-	11.21
Walnut	100 (40)	6.48	4.5	49.00
Rus. olive	7 (40)	4.30	2.8	29.13
Walnut	95 (40)	7.44	4.3	52.10
Pea shrub	40 (40)	1.70	1.2	0.50
Walnut	100 (40)	6.52	3.6	48.51
Honeysuckle	90 (40)	3.51	-	32.25
Walnut	97 (40)	4.80	4.1	20.48
Gin. maple	100 (40)	4.28	-	24.32
Walnut	95 (40)	4.83	4.1	23.11
Scots pine	57 (40)	3.88	4.4	18.38
Walnut	95 (40)	4.90	5.5	21.27
Walnut int.	89 (80)	5.22	5.0	20.98
Walnut	94 (80)	5.09	5.2	20.73

nodular symbionts with photosynthate to support fixation of atmospheric nitrogen (Dawson and Gordon 1979). Middle values for walnut growth occurred in interplantings with nitrogen-fixing trees having smaller crown volumes and in an interplanting with a non-nitrogen fixing tree with a large crown volume. Walnut growth was least on the uplands in check plots of pure walnut and in interplantings with small non-nitrogen fixing trees or shrubs.

Autumn olive, Russian olive, Siberian pea shrub, and Scots pine all survived and grew better on the drier, upland site than on the floodplain site. However autumn olive survival was only 50% even on the more-favorable upland site. It is common knowledge that locally-available autumn olive genotypes lack cold hardiness at this latitude in central North America. Black alder survival was greater on the upland site, perhaps because the growth and survival of interplanted walnuts, hence their probable capacity to release juglone into the soil, were less than on the bottomland site.

Growth of black walnut in the bottomland plots was at least three times greater overall than walnuts in the upland plots (Tables 2 and 4). Early detection of increased walnut growth associated with this experimental interplanting was possible only at the bottomland site (Van Sambeek *et al.* 1985) where only the walnut interplanted with alder had begun to significantly differentiate from any of the other interplanting treatments during the fifth, sixth, and seventh growing seasons.

Table 6.—Mean survival percentage and dimensions of 12- to 14-year-old walnut trees and nurse trees interplanted in equal proportions in upland plots with 3 x 3-m spacing

Paired species	**Survival % (initial no.)**	**Height (m)**	**Dbh (cm)**	**Crown volume (m^3)**
Alder	88 (40)	7.09	5.3	51.54
Walnut	77 (40)	3.79	2.9	4.25
Aut. olive	50 (40)	2.72	-	18.30
Walnut	77 (40)	1.61	1.7	1.08
Rus. olive	85 (40)	6.23	5.3	50.12
Walnut	70 (40)	2.83	2.6	3.79
Pea shrub	92 (40)	1.61	1.4	1.04
Walnut	57 (40)	1.22	1.3	0.56
Honeysuckle	50 (40)	1.68	-	2.22
Walnut	77 (40)	0.88	1.1	0.07
Amur maple	95 (40)	2.70	-	6.74
Walnut	70 (40)	1.04	1.1	0.25
Scots pine	92 (40)	4.58	4.1	43.41
Walnut	57 (40)	1.76	1.7	0.51
Walnut int.	80 (80)	1.13	1.1	0.20
Walnut	70 (80)	1.06	1.0	0.28

In bottomland plots the four nitrogen-fixing species were superior to the other interplanted nurse crops and the walnut check plantings in promoting walnut growth. In the upland plots alder promoted walnut growth to a greater extent than did Russian olive, autumn olive or Siberian pea shrub. The difference in the ability of bottomland and upland Russian olive interplantings to promote walnut growth relative to black alder may be due to the absence of actinorhizal nodules on Russian olive on the upland site, while Russian olive trees on the bottomland site and alder on both sites were nodulated and fixing nitrogen (Zitzer and Dawson 1989). Siberian pea shrub and autumn olive were observed to be nodulated only on the bottomland site, but were not systematically sampled, tested for nitrogen-fixation activity, nor carefully studied for patterns of nodulation as were the other two nitrogen-fixing species (Zitzer and Dawson 1989, 1992). The upland site had an acidic soil pH of 5.4 compared to a more neutral pH of 6.8 on the bottomland site (Zitzer and Dawson 1992), and pH optima for both actinorhizal and rhizobial nodulation are generally near neutral (Gordon and Wheeler 1983).

It is important to examine host plants capable of symbiotic nitrogen fixation for nodulation and nodule effectivity before assuming that they are symbiotically fixing nitrogen. It is possible for a host plant to have nodules ineffective at fixing nitrogen. It is also possible that a host plant can lack nodules but grow better on a suitable site than nodulated plants on an unsuitable site. In this study bottomland, nodulated Russian olive were visibly less vigorous but apparently better able to promote the growth of associated walnut trees than larger, more-vigorous, but non-nodulated Russian olive at the upland site. Walnut growth was enhanced by woody nurse crops in this study even where there was poor survival of some of the nurse crops after 12 to 14 years. Earlier nurse benefits have probably been carried over in these cases. In fact, death of a nitrogen-fixing tree can accelerate the rate at which fixed nitrogen is released into the soil from host tissue (Dawson *et al.* 1983), and the effects of nitrogen taken up by a tree can last a number of years due to internal nitrogen conservation mechanisms (Kramer and Kozlowski 1979).

In these two experiments, walnut growth is shown to be significantly greater than in check plots only where interplanted with nitrogen-fixing nurse crops (Tables 1 and 3). The difference is particularly distinct for estimated crown volume of walnuts. The experiment employing non-nitrogen fixing nurse treatments was established two years later than the nitrogen-fixing nurse planting experiment. However, the age difference between experiments cannot likely account for differences in experimental results because growth values for check plots established at each of the two planting dates did not differ from one another (Tables 1 and 3). Furthermore, values for walnut check-plot growth in the two experiments are similar not only to one another, but also to the walnut growth values for the non-nitrogen fixing nurse treatments (Tables 1 and 3).

Interplanting black walnut with four different nitrogen fixing, woody nurse crops significantly increased walnut growth, whereas walnut growth was not increased in a companion experiment in which walnut was interplanted with non-nitrogen fixing, woody nurse crops. Walnut trees at a floodplain site had better survival and at least three times the growth overall of walnut trees at an eroded upland site. Nurse species and walnut trees varied in survival, growth and nitrogen fixation ability with site confirming the primary importance of site selection in silviculture. Woody nurse crops capable of symbiotic nitrogen fixation can increase the growth of black walnut trees compared to walnut check plantings and non-nitrogen fixing nurse crops on sites considered good to marginal for black walnut.

ACKNOWLEDGEMENTS

We acknowledge and thank Dr. W. J. Rietveld, R. C. Schlesinger and F. Ponder of the North Central Forest Experiment Station, USDA Forest Service for their contributions in establishing experimental plots, and thank University of Illinois students K. E. Elsey, M. A. Holtzscher and M. S. Russell for their technical assistance. This research was partially supported by funds from cooperative research agreement 23-92-12 between the USDA Forest Service and the Illinois Agricultural Experiment Station.

REFERENCES

Carroll County Soil Survey. 1975. USDA Soil Conservation Service with Illinois Agricultural Experiment Station, Univ. of Illinois, Urbana. 138 p.

Champaign County Soil Survey. 1982. USDA Soil Conservation Service with Illinois Agricultural Experiment Station, Univ. of Illinois, Urbana. 178 p.

Dawson, J.O. and J.C. Gordon. 1979. Nitrogen fixation in relation to photosynthesis in Alnus glutinosa. Bot. Gaz. (Chicago) 140 (suppl.): 70-75.

Dawson, J.O., P.J. Dzialowy, G.Z. Gertner and E.A. Hansen. 1983. Changes in soil nitrogen concentration around Alnus glutinosa in a mixed, short-rotation plantation with hybrid Populus. Can. J. For. Res. 13: 572-576.

Ford-Robertson, F.C. 1971. Terminology of Forest Science, Technology, Practice, and Products. Soc. Am. For., Washington, DC. 349 p.

Friedrich, J.M. and J.O. Dawson. 1984. Soil nitrogen concentration and Juglans nigra growth in mixed plots with nitrogen-fixing Alnus, Elaeagnus, Lespedeza, and Robinia species. Can. J. For. Res. 14: 864-868.

Gordon, J.C. and C.T. Wheeler. 1983. Biological Nitrogen Fixation in Forest Ecosystems: Foundations and Applications. Martinus Nijhoff/Dr. W. Junk Publ., The Hague, Netherlands. 342 p.

Heiligman, R. and G. Scnheider. 1975. Black walnut seedling growth in wind protected microenvironments. For. Science 21: 293-297.

Kramer, P.J. and T.T. Kozlowski. 1979. Physiology of Woody Plants. Academic Press, New York. 811 p.

Losche, C.K. 1973. Selecting the best available soils. In Proceedings of the Symposium on Black Walnut as a Crop. USDA forest Service, North Central Forest Experiment Station, St. Paul. General Technical Report NC-4. pp. 33-35.

Losche, C.K., W.M. Clark, E.E. Voss and B.S. Ashley. 1980. Guide to the Selection of Soil Suitable for Growing Black Walnut in Illinois. USDA Forest Service, Northeastern State and Private Forestry Special Publication, St. Paul. 45 p.

Ponder, F. 1980. Soil properties under pure and mixed plantings of young black walnut. In Proceedings of the Third Central Hardwood Forest Conference, H.E. Garrett and G.S. Cox, eds. School of Forestry, Fisheries and Wildlife, Univ. of Missouri, Columbia. pp. 83-90.

Rietveld, W.J. 1983. Allelopathic effects of juglone on germination and growth of several herbaceous and woody species. J. Chem. Ecol. 9: 295-308.

Rietveld, W.J., R.C. Schlesinger and K.J. Kessler Jr. 1983. Allelopathic effects of black walnut on European black alder coplanted as a nurse species. J. Chem. Ecol. 9: 1119-1133.

SAS Institute, Inc. 1985. SAS User's Guide: Statistics, Version 5 Edition. Cary, North Carolina. 956 p.

Schlesinger, R.C. and R.D. Williams. 1984. Growth response of black walnut to interplanted trees. For. Ecol. Management 9: 235-243.

Van Sambeek, J.W., R.C. Schlesinger, F. Ponder and W.J. Rietveld. 1985. Actinorhizal species as nurse crops for black walnut. In Proceedings of the Fifth Central Hardwood Forest Conference, J.O. Dawson and K.A. Majerus, eds. Department of Forestry, Univ. of Illinois, Urbana. pp. 257-263.

von Althen, F.W. 1989. Early height growth increased in black walnut-silver maple intermixtures. In Proceedings of the Seventh Central Hardwood Forest Conference, G. Rink and C. A. Budelsky eds. USDA Forest Service, North Central Forest Experiment Station, St. Paul. General Technical Report NC-132. pp. 170-174.

von Althen, F.W. and J.D. Nolan. 1988. Performance of black walnut-white pine plantations in southwestern Ontario. Gov't of Canada, Canadian Forest Service, Sault Ste. Marie, Ontario. Joint Report No. 13. 30 p.

Williams, R.D. 1990. Black Walnut Juglans nigra L. In Silvics of North America: 2. Hardwoods, R. M. Burns and B. H. Honkala, tech. coords. Agriculture Handbook 654. U.S. Department of Agriculture, Forest Service, Washington, DC. pp. 391-399.

Zitzer, S.F. and J.O. Dawson. 1989. Seasonal changes in nodular nitrogenase activity of Alnus glutinosa and Elaeagnus angustifolia. Tree Physiol. 5: 185-194.

Zitzer, S.F. and J.O. Dawson. 1992. Soil properties and actinorhizal vegetation influence nodulation of Alnus glutinosa by Frankia. Plant and Soil 140: 197-204.

A Review and Validation of the Implan Model for Pennsylvania's Solid Hardwood Product Industries

Bruce E. Lord and Charles H. Strauss[1]

Abstract: The IMPLAN model for Pennsylvania was reviewed with respect to the industries processing the state's solid hardwood resources. Several sectors were found to be under represented in the standard sources of industrial activity. Further problems were attributed to the lack of distinction between hardwoods and softwoods in the national model. A further set of changes was made to update this set of industries.

INTRODUCTION

Pennsylvania's hardwood resources are processed by a variety of industries in converting raw timber to finished goods. A detailed input-output model of Pennsylvania economy was used to study the structure of these industries. The model described each processing sector in terms of its inputs and products, and the origin or direction of their flow. In-state sales and purchases were further evaluated on the basis of the export and import of products. In addition, the economic contribution of each industry was identified in terms of its value added and associated employment.

THE SOLID HARDWOOD PRODUCT SECTORS

Eleven industrial sectors have been identified as the principal solid hardwood processing groups for this study. The first element or stage of operations involves the logging camps and logging contractors sector (SIC code 2411). Within this stage, the timber resources are harvested and marketed to the primary processing sectors. At the primary processing stage, raw logs are converted to primary products, usually lumber, which in turn serves as an input to the secondary hardwood processing sectors. Examples of primary processors are sawmills and planing mills (SIC code 2421) and hardwood dimension and flooring mills (SIC code 2426). The wood pallets and skids industry (SIC 2448) also functions as a primary processor, though it's contributions to secondary processing is in the form of packaging and shipping units. Among the secondary processing sectors considered in this study are millwork (SIC 2431) and wood kitchen cabinets (SIC 2434). Typically, these sectors provide semi-finished and finished products for the home construction industries. Other major secondary industries included in this study are the wood household furniture (SIC 2511), wood TV and radio cabinets (SIC 2517), upholstered household furniture (SIC 2512), wood office furniture (SIC 2521), and public building furniture (SIC 2531). A major portion of these industries' sales are to the final demand sectors of the economy.

---

[1] Research Assistant, School of Forest Resources, The Pennsylvania State University, University Park, PA 16802; and Professor, School of Forest Resources, The Pennsylvania State University, University Park, PA 16802

DESCRIPTION OF THE IMPLAN MODEL

IMPLAN, "IMpact analysis for PLANning," has been chosen as the input-output model for this study. The IMPLAN model was designed by the Forest Service to estimate the regional economic impacts of the forest management plans for the USDA Forest Service Nation's Forests (Alward et al. 1985).

IMPLAN follows the typical non-survey approach to input-output modeling. The model relies on two sets of data. The first of these is a 528 sector input-output transactions table based upon the Bureau of Economic Analysis National I-O table (USDC 1984b). This describes the intermediate utilization and production of commodities by United States manufacturers and represents a highly disaggregated description of the average sectored input and output technologies. In addition, the model identifies the employment and industrial output levels for a potential set of 528 sectors within each county of the United States. Also included at the county level are the components of final demand and value-added for each of the sectors. Sources for the county level data include: Agricultural Statistics (USDA 1987), Census of Agriculture (USDC 1985), Census of Housing (USDC 1982), Census of Governments (USDC 1984a), County Business Patterns (USDC 1983) and Dun and Bradstreet (1982) (USDA Forest Service 1985).

Version II of IMPLAN, released in 1986, contained several improvements, some of which are significant to this study. A major modification was the adoption of an industry-by-commodity accounting framework consistent with the United Nation's System of National Accounts (Alward et al. 1985). This identifies the total production for any given commodity, above and beyond the production level of the industry for which the product is typical. For example, companies within the sawmill sector may also produce dimension stock and/or pallets. Accordingly, the industry-by-commodity format includes the sawmill sector's output of dimension and pallet products, in addition to sawn lumber. This format can also be used to accommodate different assumptions about the production technologies of the industries and commodities in question (Miller and Blair 1985, Bulmer-Thomas 1982, Gigantes 1970).

The Pennsylvania economy, as estimated by IMPLAN, was initially based upon a national technology matrix of inter-industrial relationships for the year 1982. No modifications were made to the production functions of individual industries. IMPLAN then regionalized the national input-output matrix based upon the primary inputs and final demands for as many as 528 sectors within the Pennsylvania economy. In addition, regional information about employment and the total output of the industries was used in the regionalization process. A final input to the regionalization process was the estimate of commodity demands that could be satisfied locally. These regional purchase coefficients (RPC's) are a primary determinate in the calculations of domestic imports and exports. Overall, the accuracy of the model is directly dependent upon the reliability of such regional data.

One significant limitation of the IMPLAN system is its aggregation of hardwood and softwood timber. Since these are not close substitutes for most applications, a mistreatment of intra-regional trade can result. For example, the millwork sector uses large volumes of softwoods in the manufacture of doors, windows, and moldings. However, IMPLAN, using national averages, assumes that the millwork sector obtains its inputs in regional markets. Since little softwood is grown in Pennsylvania, this leads to erroneous conclusions.

The IMPLAN user can modify many aspects of the model. Alternate data sources can be used to better estimate the value of primary inputs and final demands within the region. These values may be further modified with improved estimates of the total output and employment for regional industries. The RPC's for regional commodities may also be re-specified by the investigator. The production functions in the technology matrix may also be changed. In addition, sectors can be further aggregated or disaggregated, if desired.

REVISIONS TO THE PENNSYLVANIA IMPLAN MODEL

An allied objective within this study was to evaluate and improve the accuracy of the IMPLAN model in depicting the hardwood product industries. The upgraded model was based on the Pennsylvania economy in 1987, the latest year for which data was commonly available. Several sets of modifications were made, including:

(1) Update of employment, value added, and total output levels for all industrial sectors to a 1987 basis.
(2) Review and revision of the forest product sectors for reporting errors.
(3) Review and revision of regional purchase coefficients for all industrial sectors and, in particular, the forest product sectors.
(4) Revision of final demands for all products and services by the household and government sectors.
(5) Adjustment of all monetary values associated with the 1982 IMPLAN model to a 1987 basis.

Updating of Employment and Output Levels

Non-agricultural employment was revised to a 1987 basis (Penna. Bureau of Labor Statistics 1989) and subsequently used as an indicator for updating the output and value added for each respective industrial sector. In the case of the agricultural sectors, the commodity outputs were revised to a 1987 basis (USDC 1989), with these values used as indicators of the relative changes in employment and value added within the agricultural sectors.

As a further step in the review process, the productivity changes for U.S. industries over the 1981-1987 period were identified. These changes in output per employee were used to further adjust output and value added estimators within the non-agricultural sectors. In the case of the agricultural sectors, the productivity changes were used to further revise employment estimates.

Revisions to the Forest Product Sectors

Certain forest product industries, notably logging and sawmilling, have the potential of being under reported due to their workers not receiving coverage in various government unemployment and insurance programs. A 1981 I-O survey of all forest product industries in an eight county region of north central Pennsylvania (Westman et al. 1985) was compared to an IMPLAN model of the same region to estimate the extent of under reporting in the state-wide model. Ratios for employment, employee compensation, value added and total industrial output were established between the two models and subsequently applied to the Pennsylvania IMPLAN model for purposes of revising the state's forest product industries. Additional revisions were extended to Pennsylvania's wood pallet industry based upon a recent state-wide survey of this industry (Fraser 1985).

Regional Purchase Coefficients and Further Output Adjustments

The regional purchase coefficients for in-state timber and lumber products among the forest product sectors were reviewed and adjusted based upon related studies of these sectors and the inherent characteristics of the state's timber resources and allied industrial demands. The RPC's for log inputs to the sawmill, dimension mill, millwork, and kitchen cabinet sectors were increased to 0.85. These changes were in accordance with the study by Westman et al. (1985), and a general understanding of the hardwood industries in Pennsylvania. The wood pallet sector was constrained to purchase only in-state inputs with an RPC for lumber of 1.0. This reflected the sector's traditional use of low grade hardwoods from local markets (Fraser 1985). Although paper and paperboard mills were outside this study, their demand for log inputs had a direct impact on the logging sector. Accordingly, the paper mill RPC's for log input was set at 0.50 to reflect their purchase of hardwood fiber from in-state sources. The remainder of their log input, representing softwood fiber, was met by out-of-state sources.

The net effect of the RPC changes for log input was an unreasonably high import of hardwood logs from adjoining states. In order to more accurately reflect the timber production level within Pennsylvania, in-state production was increased by about 20%, thereby reducing timber imports to a more reasonable level and generating an expected volume of domestic log exports.

In a similar manner, the forestry sector, representing the owners of timber, had an insufficient output level for supporting the now enlarged logging sector. Since the RPC for in-state timber was already set at 0.9, the output level of this sector was increased until a reasonable import-export profile was observed.

Other anomalies within the Pennsylvania IMPLAN model were the specification of zero RPC's for the output from several major industrial sectors outside the forest products group. This included the electric service sector, wholesale and retail sectors, and the eating and drinking place sector. In effect, all of their output would be sold to export markets. These RPC's were subsequently reset to 0.6, in correspondence with the RPC's of similar products from allied sectors within Pennsylvania's economy.

Final Demand Updates

Changes in the level of Personal Consumption Expenditures (U.S. Department of Commerce 1988), Federal Budgets (US Treasury Department 1988), and State Budgets (Pennsylvania Office of the Budget 1987) were used to update household and government demands to 1987 levels. Since these purchases were not specified by industry, averages were used, leaving the distribution of expenditures among industrial sectors unchanged from their original 1982 levels.

Foreign export levels for the manufacturing sectors were obtained at a two digit SIC level for 1982 (Pennsylvania Department of Commerce 1987). These values were used to update this component of final demand, with the changes distributed proportionally within the two digit aggregates.

Inflation Adjustments

A final adjustment to the Pennsylvania model involved the updating of all values to 1987 dollars. Commodity prices were obtained from the Bureau of Labor Statistics (U.S. Department of Labor 1988) for the period 1981-1986. An additional adjustment was made using OECD inflation indices to get the figure into 1987 dollars (OECD 1988). These inflation values were applied throughout the model on a commodity-by-commodity basis to develop figures comparable with the 1987 fiscal year.

RESULTS

The size and stature of the solid hardwood product industries can be measured in several ways. A gross indication of size comes from the total output, or sales of each industry (Table 1). The SHP industries had estimated sales in 1987 of almost $3 billion. This represented 2.1 percent of the total sales among all manufacturing industries in Pennsylvania, and 0.9 percent of all industrial sales in the state. Within the SHP industries, the sawmill sector had the most sales ($845 million), followed by the logging sector ($580 million) and the kitchen cabinet sector ($490 million).

Table 1.—Pennsylvania's economy in 1987

Industrial sector	**Total sales**		**Value added**		**Wages & salaries**		**Employment**	
	Millions of dollars						(# of Jobs)	
		Pct. of SHP Industries		Pct. of SHP Industries		Pct. of SHP Industries		Pct. of SHP Industries
Agriculture, forestry and fisheries	$3,882		$1,291		$546		95020	
Mining	$6,382		$3,487		$1,516		26903	
Construction	$14,956		$6,129		$5,445		181652	
Manufacturing (less hardwood industries)	$137,182		$48,175		$36,723		1023409	
Solid hardwood product industries	$2,987		$1,174		$716		38121	
160 - Logging camps and logging contractors	$580	19.42%	$206	17.58%	$92	12.86%	4794	12.58%
161 - Sawmills and planing mills, general	$845	28.30%	$365	31.13%	$173	24.14%	9796	25.70%
162 - Hardwood dimension and flooring mills	$159	5.31%	$80	6.82%	$41	5.78%	2799	7.34%
164 - Millwork	$256	8.56%	$67	5.74%	$52	7.32%	2942	7.72%
165 - Wood kitchen cabinets	$490	16.41%	$190	16.14%	$162	22.62%	6358	16.68%
170 - Wood pallets and skids	$151	5.05%	$63	5.37%	$37	5.22%	2406	6.31%
174 - Wood household furniture	$222	7.45%	$92	7.81%	$71	9.94%	4432	11.63%
176 - Wood TV and radio Cabinets	$14	0.47%	$5	0.42%	$5	0.66%	319	0.84%
177 - Upholstered household furniture	$104	3.49%	$41	3.49%	$34	4.71%	1659	4.35%
180 - Wood office furniture	$137	4.60%	$54	4.62%	$40	5.54%	2192	5.75%
182 - Public building furniture	$28	0.94%	$10	0.88%	$9	1.21%	424	1.11%
Transportation, Communications and Utilities	$32,234		$16,823		$8,381		231832	
Wholesale and Retail Trade	$19,173		$13,766		$8,793		872296	
Finance, Insurance and Real Estate	$32,426		$18,601		$8,993		288766	
Services	$75,781		$44,274		$31,424		1476055	
Government Enterprises	$4,482		$2,399		$2,504		87353	
Special Industries	$15,754		$15,754		$13,795		706154	
Total	$345,239			$171,875		$118,835		5027561

Table 2.—Imports and exports of Pennsylvania's hardwood products

Solid hardwood sectors	**Regional consumption of regional production**	**Foreign export**	**Domestic export**	**Total regional output**	**Total regional consumption**	**Regional imports**	**Net domestic export/import**
160 - Logging camps and logging contractors	$485.1	$10.1	$110.1	$604.1	$636.1	$141.1	-$31.1
161 - Sawmills and planing mills, general	$378.1	$17.1	$437.1	$832.1	$651.1	$255.1	$181.1
162 - Hardwood dimension and flooring mills	$61.1	$1.1	$87.1	$149.1	$85.1	$24.1	$64.1
164 - Millwork	$124.1	$2.1	$148.1	$274.1	$149.1	$23.1	$126.1
165 - Wood kitchen cabinets	$51.1	$1.1	$429.1	$481.1	$54.1	$3.1	$427.1
170 - Wood pallets and skids	$33.1	$1.1	$107.1	$140.1	$36.1	$3.1	$104.1
174 - Wood household furniture	$195.1	$28.1	$0.1	$222.1	$357.1	$134.1	-$134.1
176 - Wood TV and radio Cabinets	$6.1	$3.1	$7.1	$15.1	$11.1	$3.1	$5.1
177 - Upholstered household furniture	$100.1	$5.1	$0.1	$105.1	$242.1	$137.1	-$137.1
180 - Wood office furniture	$37.1	$5.1	$81.1	$123.1	$52.1	$10.1	$71.1
182 - Public building furniture	$18.1	$0.1	$18.1	$37.1	$46.1	$28.1	-$10.1

The contribution of an industry to the state's economy can also be measured by its value added. This measures the benefits accruing to employees as wages and salaries, to industrial ownership as profits, and to the government sector as taxes and transfers. The SHP industries contributed over $1.1 billion to Pennsylvania's gross product of $176 billion, including 0.6 percent of the total value added to the state economy and 2.4 percent of the value added contributed by manufacturing. The largest individual contributors of value added were again the sawmill sector ($365 million), the logging sector ($206 million) and the kitchen cabinet sector ($190 million).

Other measures of an industry's importance to society are the people hired and the wages they received. The SHP industries paid out $716 million in wages and salaries to over 38,000 employees in 1987. This represented 1.9 percent of manufacturing wages and 3.6 percent of manufacturing jobs in the state. Overall, these industries represented 0.6 percent of all wages and 0.8 percent of all jobs in the state. The leading SHP sectors in wage payments were the sawmill sector ($173 million), the kitchen cabinet sector ($162 million) and the logging sector ($92 million). In terms of employment, these sectors supplied 9796, 6358, and 4794 jobs, respectively.

SUMMARY OF THE INPUT-OUTPUT CHARACTERISTICS OF THE SHP GROUP

A review of the commodity balances for the solid hardwood products is provided in Table 2. The net trade deficit registered in logging products was largely due to the import of softwood fiber for paper manufacturing. In terms of hardwood logs, Pennsylvania was a net exporter to adjacent states and to foreign markets. A substantial domestic and foreign export of sawmill products was also evident. The general viability of Pennsylvania's hardwood forest as a raw material base was evident in the export of $119 million in logs and $454 million in sawmill products. In part, the prominence of hardwood lumber was partially masked by the import of softwood lumber for residential home building.

Dimension and flooring, and pallet products, largely represented a subsidiary component of sawmill products. As a means of increasing the sale of middle and lower grades of lumber, additional manufacturing was involved in this set of products. Substantial export was evident among these products, with dimension having a gross export of $88 million and pallets of $107 million.

Although millwork proved to be another major source of net exports, there was some question whether this group of products was dependent on hardwood resources. The focus on windows, doors, and allied residential building products suggested that these were largely softwood products, having limited ties to Pennsylvania's forests.

At the secondary processing level, two products showed a certain competitive advantage for Pennsylvania; kitchen cabinets and wood office furniture. Kitchen cabinets had a net domestic export of $427 million and office furniture of $71 million. Both product groups utilized substantial volumes of hardwood input from Pennsylvania. However, they also used a wide array of other inputs, including plastics, hardware, paints, and softwood-based products. In all probability, the regional advantage enjoyed by the kitchen cabinet industry was closely linked with the residential housing market along the East Coast.

Only limited economic advantages were evident among the remaining secondary products, namely wood household, upholstered, and public building furniture. As a group, their manufacture amounted to $363 million. However, the regional market for these products was $645 million, with $281 million in products imported to Pennsylvania.

CONCLUSIONS

The IMPLAN model for Pennsylvania's economy was compared with other independent data sources. Several sets of modifications were required to provide a realistic description of the state's solid hardwood product industries. The small firm size of some processing sectors removes them from having to report their employment to state unemployment insurance programs, a key source of activity levels for the regional IMPLAN data sets. The lack of distinction between hardwoods and softwoods in the model's data sets, meant that the regional purchase of these products was misstated.

The sawmill and planning mill industry was the largest component of the solid hardwood sectors. Additional sectors of significance included the logging sector, the kitchen cabinet sector and the household furniture sector. In terms of bringing outside income into the state, the kitchen cabinet sector provided the greatest impacts. The wood household furniture and the upholstered furniture sectors were large net import sectors, and consequently represent opportunities for expansion in the state economy.

LITERATURE CITED

Alward, G.S., H.C. Davis, K.A. Despotakis, and E.M. Lofting. 1985. "Regional non-survey input-output analysis with IMPLAN." Paper presented at the Southern Regional Science Association Conference. Washington, DC. May 9-10, 1985.

Bulmer-Thomas, V. 1982. Input-Output Analysis in Developing Countries. John Wiley and Sons Ltd. New York, NY.

Doud, L.F. 1990. The Kitchen Cabinet Industry in Pennsylvania in 1987. Thesis (M.S.) The Pennsylvania State University, University Park, PA.

Dun and Bradstreet Marketing Corporation. 1982. Dun's Census of American Business. Dun's Marketing Services, Dun and Bradstreet Corporation. Parsippany, NJ.

Fraser, Rory. 1985. The Pallet Industry in Pennsylvania in 1986.Thesis (M.S.) The Pennsylvania State University, University Park, PA

Gigantes, T. 1970. "The representation of technology in input-output analysis," in Contributions to Input-Output Analysis, Vol. 1. A.P. Carter and A. Bròdy eds. North-Holland Publishing Company. Amsterdam.

Miller, R.E. and P.D. Blair. 1985. Input-Output Analysis: Foundations and Extensions. Prentice-Hall, Englewood Cliffs, NJ.

Office of Management and Budget. 1987. Standard Industrial Classification Manual. Executive Office of the President, Office of Management and Budget, Washington, DC.

Organization for Economic Cooperation and Development. 1988. Main Economic Indicators. OECD, February 1988. Paris.

Palmer, C., E. Siverts, and J. Sullivan. 1985. IMPLAN Version 1.1: Analysis Guide. USDA Forest Service, Land Management Planning Systems Section. Fort Collins, CO.

Pennsylvania Bureau of Labor Statistics. 1989. "Pennsylvania ES-202 Report." Unpublished employment data for first quarter of 1988. Harrisburg, PA.

Pennsylvania Department of Commerce, Bureau of Domestic and International Commerce. 1987. "Products exported by Pennsylvania manufacturers: 1982," in 1987 Pennsylvania Statistical Abstract. The Pennsylvania State Data Center. Middletown, PA.

Pennsylvania Office of the Budget, Bureau of Financial Management. 1987. "General fund expenditures of the Commonwealth of Pennsylvania," in 1987 Pennsylvania Statistical Abstract. The Pennsylvania State Data Center. Middletown, PA.

U.S. Department of Agriculture. 1987. Agricultural Statistics. U.S. Department of Agriculture. Washington, DC.

U.S. Department of Commerce. 1982. 1980 U.S. Census of Population and Housing. U. S. Department of Commerce, Bureau of the Census, Washington, DC.

U.S. Department of Commerce. 1983. "1972 County Business Patterns," (computer tapes). U.S. Department of Commerce, Bureau of the Census, Economic Surveys Division, Washington, DC.

U.S. Department of Commerce. 1984a. Census of Governments. U.S. Department of Commerce, Bureau of the Census, Washington, DC.

U.S. Department of Commerce. 1984b. The Detailed Input-Output Structure of the U.S. Economy, 1977. The Use and Make of Commodities by Business. Vol. 1. U.S. Department of Commerce, Bureau of Economic Analysis, Washington, DC.

U.S. Department of Commerce. 1984c. Census of Manufacturers: 1982. U. S. Department of Commerce, Bureau of the Census, Washington, DC.

U.S. Department of Commerce. 1985. Census of Agriculture: 1982. U.S. Department of Commerce, Bureau of the Census, Washington, DC.

U. S. Department of Commerce, Bureau of Economic Analysis. 1988. "Personal consumption expenditures in the U. S.," in The World Almanac and Book of Facts 1989. Pharos Books. New York, NY.

U.S. Department of Commerce. 1989. Schedule B: Statistical Classification onä of Domestic and Foreign Commodities Exported and Imported from the United States Database. Bureau of the Census. Washington, DC.

U. S. Treasury Department. 1988. "U. S. net receipts and outlays," in The World Almanac and Book of Facts 1989. Pharos Books. New York.

U.S. Department of Commerce 1989. Census of Agriculture: 1987. U.S. Department of Commerce, Bureau of the Census, Washington, DC.

U.S. Department of Labor, Bureau of Labor Statistics. 1988. "Time Series Data for Input-Output Industries—Output, Price, and Employment." Unpublished data available from Office of Economic Growth and Employment Projections. Washington, DC.

Westman, E.D.,C.H. Strauss, R.S. Bond. 1985. A Description of the Forest Product Industries in the Allegheny Region. Research Paper No. 47, July 1985. School of Forest Resources, The Pennsylvania State University, University Park, PA.

Advance Reproduction and Other Stand Characteristics in Pennsylvania and French Stands of Northern Red Oak

Kim C. Steiner, Marc D. Abrams, and Todd W. Bowersox[1]

Abstract: The frequent scarcity of northern red oak (NRO) advance reproduction raises questions about its regeneration potential under prevailing stand conditions in eastern North America. In contrast, NRO plantations in France typically contain abundant advance reproduction. The purpose of this study was to document stand conditions in Pennsylvania (PA) and southwestern France (FR) that may be contributing to the difference in apparent regeneration potential. In each case, five mature stands or plantations were selected for study.

The density of NRO advance reproduction was 2,500/ha in PA and 271,300/ha in FR. NRO stems were taller and older on average in FR than in PA; 15% of the FR cohort but only 2% of the PA cohort had survived beyond the fifth growing season. Basal area for all species averaged about 27 m^2/ha in both regions, but NRO composed only 49% of the basal area in PA as opposed to 98% in FR. Canopy cover in June was significantly greater in PA stands by an average of 5.3%. Herbaceous ground cover averaged much higher in PA than in FR; it appeared that the abundance of advance reproduction in FR effectively excluded competition by herbaceous vegetation. Unfragmented leaf litter in May (dry weight / m^2) was over twice as great in FR than in PA. Results demonstrate that NRO can accumulate abundant advance reproduction under relatively undisturbed canopy, at least in FR. Among the factors measured in this study, lower accumulations of leaf litter in PA as compared to FR may suggest poorer conditions for overwinter survival and germination of acorns in PA. Lower herbivore pressure and marginally lower canopy shade levels in FR compared with PA probably contribute to the superior success of advance reproduction in FR.

INTRODUCTION

Oak (*Quercus*) species dominate forests in much of the eastern United States. Oak species were also important in presettlement forests of the region and were considered a climax type by early ecologists (Michaux 1853, Bromley 1935, Clements 1936, Braun 1950). Despite the fact that an occasional eastern oak forest contains abundant oak reproduction, much of the recent work indicates that oak regeneration failure is pervasive (Adams and Anderson 1980, Lorimer 1984, Host *et al.* 1987, Pallardy *et al.* 1988, Nowacki *et al.* 1990, Abrams and Downs 1990). However, low density of oak advance reproduction may be site dependent, being more apparent in mesic versus xeric forests (Abrams 1986, Nowacki and Abrams 1991). Thus, regeneration problems and probably successional replacement of the oak overstory are particularly evident in northern red oak (*Q. rubra* L.) forests, which tend to occur on mesic sites (Adams and Anderson 1980, Host *et al.* 1987, Crow 1988, Nowacki *et al.* 1990). It is economically significant that regeneration difficulties with northern red oak (NRO) appear to be especially severe in Pennsylvania, which has the largest concentration of NRO timber among states.

---

[1] Professor, Assistant Professor, and Professor, respectively, School of Forest Resources, The Pennsylvania State University, University Park, PA 16802.

Numerous plantations of northern red oak have been established in southwestern and northeastern France since the late 1800's. The French plantations çäare managed for the production of lumber or low-grade veneer on rotations of 70-80 years (Lanier *et al.* 1980), which is considerably less than the >200-year rotations required for the more valuable but slower-growing native oaks (*Q. petraea* (Matt.) Liebl. and *Q. robur* L.). Harvested stands of NRO are regenerated in France by the release of advance reproduction, which is almost universally abundant in both portions of the country where the species is commonly grown (personal observation). The purpose of this study was to document stand conditions in Pennsylvania (PA) and southwestern France (FR) that may be contributing to northern red oak's apparently inferior regeneration potential in its native range.

MATERIALS AND METHODS

Study Sites

Five stands were selected for study in each region (Table 1). Stand selections in PA were coordinated through the Pennsylvania Bureau of Forestry, which manages 13% of the commercial forest land in the state. District offices were requested to identify stands with relatively abundant advance reproduction of NRO and a minimum of 70% stocking of NRO over an area of at least 1.2 ha. District offices identified 13 candidate stands. All stands fell short of the stocking criterion, and none had "abundant" advance reproduction. However, those selected for study had the highest reproduction densities and appeared *capable* of natural regeneration based upon maturity and canopy dominance of NRO over other species. All five are in central PA: two (Nook and Alan Seeger) in the Ridge and Valley physiographic province, and three in the Allegheny Plateau province.

Candidate plantations in FR were selected through the cooperation of M. Jean Timbal, Institut National de la Recherche Agronomique, who some years previously had surveyed all known plantations of NRO in that country for a growth and yield study. Site indices for FR plantations in Table 1 come from stem analyses that he performed and were extrapolated from base age 40 using Schnur's (1937) tables. From among 30 candidate plantations visited, five were selected for study primarily on the basis of relative freedom from previous or anticipated disturbance (thinning, harvesting, mowing, or seed collection). All but one of the 30 plantations had abundant NRO reproduction by PA standards, but the five study plantations are probably above-average in this regard. One plantation (Tournebride) is in the flat Landes Region immediately south of Bordeaux, and the other four are in the hilly countryside abutting the Pyrenees.

Measurements

The density of NRO advance reproduction was measured in mid-June 1990 (FR) and early June 1991 (PA) by counting understory stems within regularly spaced transect plots. Sampling consisted of 20 3-m^2 plots per study site in FR and 20 or 40, 20-m^2 or 5-m^2 plots per site in PA, depending upon the density of stems. All advance reproduction was counted regardless of height, which was sometimes as great as ca. 3.5 m in FR. In addition, at each of 20 plots per study site, the four NRO stems closest to the plot center were measured for height, and the root age of each

Table 1.—Locations and other characteristics of natural stands in Pennsylvania and northern red oak plantations in France used as study sites. Where appropriate, standard deviations are given in parentheses.

	PENNSYLVANIA				
	Alan Seeger	**Nook**	**Smith Road**	**Firebreak**	**Wykoff Branch**
Latitude	40°42'	40°31'	41°06'	41°08'	41°28'
Longitude	77°45'	77°35'	78°33'	78°32'	77°59'
Aspect	Northwest	Northwest		South	Southeast
Slope	5°	9°		2°	2°
Elevation (meters)	351	396	686	640	625
Study area (hectares)	1.40	1.76	1.70	1.41	1.60
Basal area, NRO (m^2/ha)	12.4 (0.57)	10.6 (0.60)	14.9 (0.62)	15.4 (0.94)	12.9 (0.78)
Basal area, all species (m^2/ha)	26.9 (0.73)	26.6 (0.60)	22.0 (0.62)	31.9 (0.76)	28.9 (0.80)
Site index (meters at age 50)	23.2	24.4	19.2	22.3	20.7
Mean age of dominant NRO (years)	123	70	82	74	72
Litter dry wt (g/m^2)	371 (31.3)	476 (77.1)	195 (17.6)	236 (17.3)	289 (23.3)
NRO advance reproduction (#/ha)	70 (41)	520 (112)	8,660 (1,526)	2,300 (332)	1,150 (276)

	FRANCE				
	Vic-en-Bigorre	**Ibos II**	**Bacquieu I**	**Mixe II**	**Tournebride**
Latitude	43°24'	43°15'	43°44'	43°26	44°39'
Longitude	0°00'	0°02'W	0°03'E	1°09'W	0°44'W
Aspect	East	East	West	Northeast	None
Slope	1°	4°	2°	6°	0°
Elevation (meters)	213	396	152	91	61
Study area (hectares)	0.64	0.71	0.72	0.60	0.93
Basal area, NRO (m^2/ha)	23.6 (0.55)	26.4 (0.57)	31.0 (0.73)	33.3 (0.76)	21.1 (0.46)
Basal area, all species (m^2/ha)	same	same	same	same	23.4 (0.41)
Site index (meters at age 40)	29.9	28.3	28.3	31.4	15.8
Plantation age (years)	60	51	49	52	97
Litter dry wt (g/m^2)	698 (71.4)	741 (53.4)	588 (27.3)	752 (60.4)	529 (20.5)
NRO advance reproduction (#/ha)	239,190 (15,419)	256,240 (19,595)	253,770 (17,248)	211,520 (29,207)	395,610 (33,605)

stem was determined by counting annual rings in a section taken immediately below the soil surface. However, because of the scarcity of advance reproduction on some PA sites, as few as 30 (as opposed to 80) stems were measured and aged in this manner. Current-year germinants were counted as age 0. At the same plot centers as above, overstory basal area was estimated with a basal area factor 10 prism.

On the same dates as above, percentage canopy cover was determined by photographing the canopy directly above 6 to 10 sample points per stand. A wide-angle lens and high contrast film were used. Photographs were enlarged to 8 x 10 inches and percentage of sky obscured by canopy was determined by means of a dot grid superimposed upon the photograph.

Also on the same dates, percentage ground cover by herbaceous and woody vegetation (excluding NRO stems) was determined from 20 sample plots per stand located by transect. Sample plots were 5-m^2 (PA) or 3-m^2 (FR) circles, and percentage ground cover by vegetation category was estimated using five classes: 0-5%, 6-25%, 26-50%, 51-75%, and 76-100%.

Quantity of mulch available for over-winter acorn protection was estimated from oven-dry weights of the unfragmented leaf litter persisting from autumn 1990 until mid-May 1991. At 15 (FR) or 22-30 (PA) transect points per study site, unfragmented leaf litter from 1990 was gathered by slicing the litter around the circumference of a 318-cm^2 aluminum sampling ring. Each sample was oven-dried at 80∞C until the weight loss stabilized, and the samples were then weighed.

Observations in spring 1990 and 1991 indicated that over-winter soil turnover by earthworms may be a significant factor in burying acorns at most of the FR study sites. Piles of ca. 0.6-cm diameter castings are frequent at all FR sites except Tournebride, where the soil is exceptionally sandy and earthworms of this type seem to be absent. Casting piles may be as large as 25 cm in diameter and 8 cm in height. Nothing comparable was observed on PA sites. To estimate the extent of this phenomenon, we established sample plots at 7-8 systematically chosen locations on each study site in mid-November 1991. Each plot consisted of a 420-cm^2 plastic grid pinned to the soil surface underneath the leaf litter, which was then replaced. Each grid had 100 cells, and the fraction of these covered with new worm castings was determined 6 months later, in mid-May 1992.

RESULTS AND DISCUSSION

Stand basal areas averaged 27.3 and 27.5 m^2/ha in PA and FR, respectively ($P > 0.05$), although stocking varied considerably from stand-to-stand within each region (Table 1). NRO composed an average of 49% of stand basal area in PA and all of the basal area in FR except at Tournebride, where there was a small component of *Pinus pinaster* Ait. and *Q. robur*. Non-oak species, principally maples, made up 35% of basal area stocking in PA stands. All five FR stands have been thinned at intervals, and their current stand density probably does not reflect full site occupancy. PA stands have not been treated silviculturally.

Site indices were almost uniformly higher in FR than in PA (Table 1), but the lowest site index in the study occurred at one of the FR study areas (Tournebride). Canopy cover in June averaged 5% greater ($P < 0.001$) in PA (range 84-95%) than in FR (range 83-89%). The greater canopy cover in PA was probably due in part to the presence in PA stands of maples and other species with a greater shade tolerance than NRO, and in part to the thinnings in FR mentioned above. Although one PA stand (Smith Road) was comparable in canopy cover to FR stands, it can be concluded that the understory in PA stands is generally more shaded than in these FR stands.

Despite the slightly greater canopy cover in PA than in FR, unfragmented leaf litter dry weight in May averaged less than half as much in PA (313 g/m^2) as in FR (662 g/m^2) ($P < 0.001$) (Table 1).

This discrepancy is likely due to the presence in the PA stands of a large component of maples and other non-oak species whose leaves tend to weather more rapidly than those of oaks (Kucera 1959, McClaugherty *et al.* 1985).

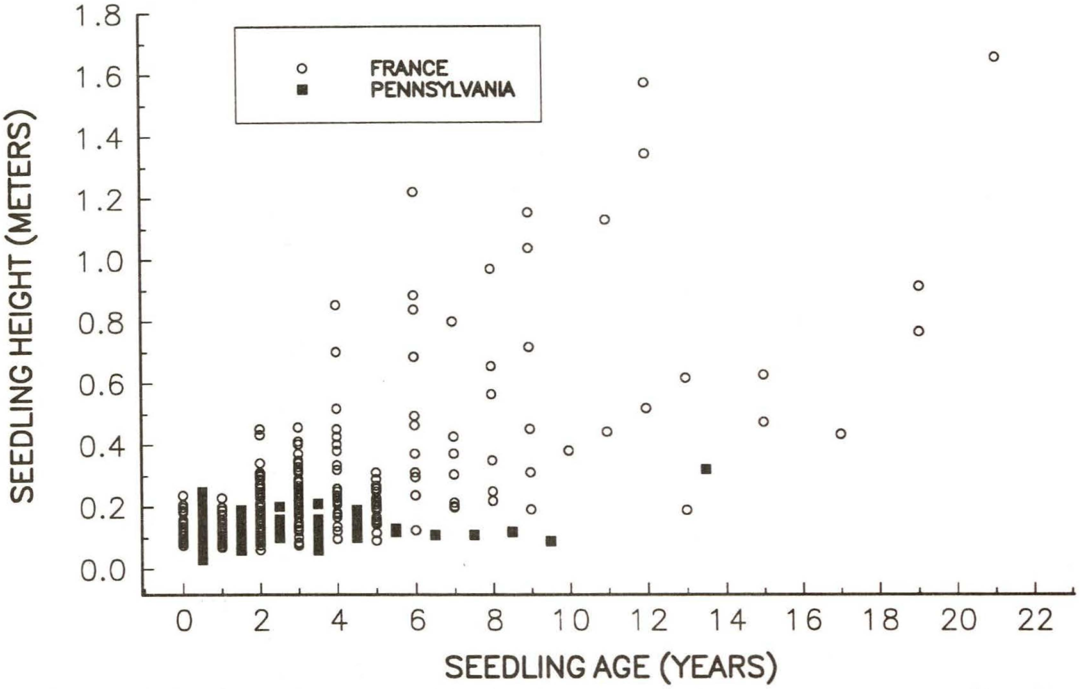


Figure 1. — Percentage of ground covered by herbaceous and woody vegetation other than northern red oak. Separate bars within a region apply to each of the five study sites, ordered from left to right in the same way as Table 1.

The percentage of ground cover by woody species other than NRO was comparable between PA and FR (ca. 6% and 8%, respectively), though somewhat variable among stands within each region (Figure 1). Herbaceous cover averaged much greater (36%) in PA than in FR (5%) but the difference was largely due to the abundance of hayscented or bracken fern at three of the PA sites. Two stands in PA had rather little herbaceous ground cover. Actually, the soil surface was probably more heavily shaded by understory vegetation in FR than in PA because of the presence in FR of an almost continuous "canopy" of NRO advance reproduction in those stands. As we show below, NRO was continuing to recruit into the advance reproduction in FR despite a very high density of woody stems in the understory. Although the heavy fern cover at three of the PA sites probably inhibits seedling establishment (Kolb *et al.* 1989, Scholz 1955, Smith and Vankat 1991), the relative absence of a woody understory in PA (including NRO advance reproduction) may more likely be the cause than the result of the generally more abundant herbaceous cover.

The greater abundance of unfragmented leaf litter in FR stands presumably contributes to better conditions for germination by protecting the acorns from desiccation (Korstian 1927) and hiding them from predators. In other research in these stands (Steiner, unpublished data) we have found the proportion of acorns in May that are exposed on top of the litter or soil to be several-fold higher in PA. Additionally, our estimates of soil turnover by earthworms indicate a surprising potential for burial through this phenomenon. On the four sites where we have seen castings, the percentage of soil surface that became covered with new castings between November and May varied from

2.3 (Mixe II) to 40.8 (Bacquieu I), with an average for all four sites of 16.6%. In addition, 4.4% of the surface at Mixe II was covered with fresh mole or rodent excavations. Although we have seen no such earthworm castings at Tournebride, its very sandy soil appears especially conducive to germination since fallen acorns tend to become at least partially buried over winter. Taken together, these conditions suggest that the forest floor in FR stands is generally more favorable for the over-winter storage and germination of acorns than it is in PA.

As noted already, the density of NRO stems was much higher in FR (271,300/ha) than in PA (2,500/ha) (Table 1). The fact that District Offices failed to find stands in PA with higher levels of advance reproduction suggests that stands with significantly higher levels are probably nonexistent on state forest lands in PA. Indeed, the density of NRO seedlings on our PA study sites is typical of densities found in other studies in upland oak stands in the eastern U. S. (Bowersox and Ward 1972, Good and Good 1972, Minckler and Jensen 1959, Nowacki *et al.* 1990, Nowacki and Abrams 1991, Dawson *et al.* 1989, Johnson *et al.* 1989, Kittredge and Ashton 1990, Tryon and Carvell 1958). We know of no reports on American stand conditions in which advance reproduction of upland oaks was even nearly as abundant as in the FR stands we studied, even after accounting for relative basal areas.

As expected, the numbers of stems of advance reproduction declined with stem age in both PA and FR stands, but the decline was much more rapid in PA (Figure 2). The relative frequencies of stems in different age classes was probably affected by the periodicity of acorn crops in previous years. For example, all five PA stands had moderate to heavy seed crops in the autumn prior to measurement, and current-year germinants (age class 0) were by far the most common class. Also, 2-year-old seedlings were the most common age class in FR probably because of a large acorn crop in autumn 1987. Thus, age-dependent survival is confounded with seed crop periodicity in Figure 2.

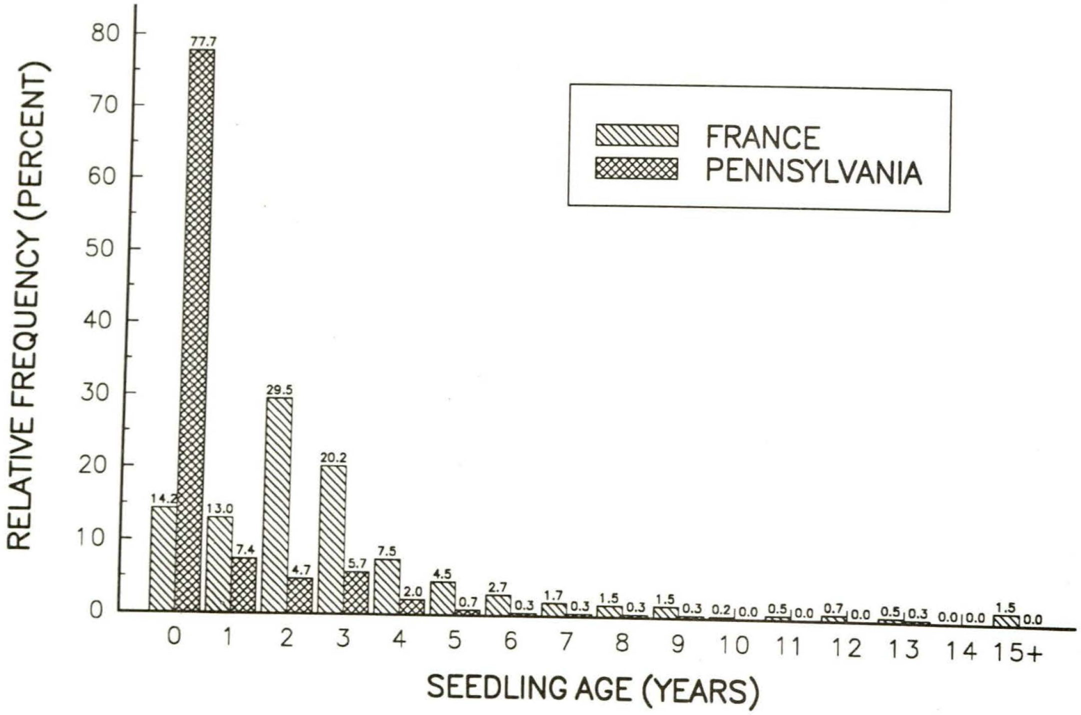


Figure 2. — Age-class distribution of stems of northern red oak advance reproduction in PA stands (n = 296 seedlings) and FR plantations (n = 400 seedlings), as sampled in June. Current-year germinants are age class zero. Numbers above bars are actual percentages.

Nevertheless, it seems apparent that advance reproduction is surviving longer in FR stands than in PA stands. Some 15% of FR stems had survived beyond the fifth growing season after germination, but only 2% of the PA seedlings had done so. Even an exceptionally large acorn crop in FR could hardly put half the stems in age class 0, and thereby reduce other age class frequencies by half. Likewise, even if there had been no autumn 1990 seed crop in PA, only 10% of PA stems present in spring 1991 would have been >5 years old. In contrast, other studies in the U.S. have shown better survival over time than appears to be occurring in our Pennsylvania stands. Good and Good (1972) observed only 16% mortality in each of the first two years for NRO seedling cohorts in a New Jersey woodland unaffected by deer browsing; survival after five seasons of growth would be 42% if the same annual rate continued. Beck (1970) found that 24% of NRO seedlings survived for 6 years under an overstory in North Carolina plots (see also Loftis 1988).

Although forest floor light levels can be limiting to NRO seedling survival and growth (Sander 1990), and overstory canopy cover was generally more dense in PA stands, we do not believe this accounts for the apparently more rapid mortality of seedlings in those stands as compared with FR. Regardless of overhead canopy, there was in FR stands a virtually complete "canopy" of NRO advance reproduction over the ground. The dominant portion of this understory consisted of a small proportion of larger seedlings and saplings, so most of those randomly sampled for aging were shaded by this canopy as well as by the overstory. As a result, the average seedling in FR was probably more heavily shaded than the average seedling in PA, though we have no data to document it. The faster mortality of PA seedlings is probably attributable to deer browsing, which can be severe in PA but is light in the FR stands we have observed.

The likelihood that NRO advance reproduction will actually contribute to regeneration following overstory removal is dependent upon seedling size (Loftis 1990, Sander 1971, Sander 1972, Sander *et al.* 1984). For example, Loftis (1990) used seedling size to predict the probability that an individual stem would produce a dominant or codominant tree at 20 years after harvest. None of the seedlings in PA stands were over 0.3 m in height (Figure 3), and Loftis' model suggests that no more than a very small percentage, if any, could actually contribute to stand regeneration. Although relatively few NRO stems in FR exceeded a meter in height (Figure 3), the absolute number per hectare was large (ca 4,700) due to the overall abundance of advance reproduction. None were represented in our samples, but most FR stands had many stems exceeding 2 m in height. Since NRO advance reproduction dominates the understory vegetation in these FR stands, there is little doubt that the stands would become fully restocked with NRO if harvested.

CONCLUSIONS

Seedling establishment in FR probably benefited from favorable conditions for overwinter storage of acorns, including relatively abundant leaf litter and the unusual soil turnover activity of large earthworms. This may help explain the abundance of seedlings in FR (though other factors such as acorn production and predation are probably also important), but it does not explain their persistence.

Overstory canopy density was slightly but significantly higher in PA than in FR, as was the mean percentage of forest floor occupied by herbaceous and woody plants other than NRO. However, two PA stands had light ground cover, and most of the sampled stems in FR were beneath a canopy of advance reproduction (since younger and thus smaller seedlings were much more frequent). Shade from ground vegetation probably does not account for the relative absence of regeneration in PA; in fact, the generally greater abundance of herbaceous ground vegetation in PA may instead be a consequence of the paucity of woody plant regeneration.

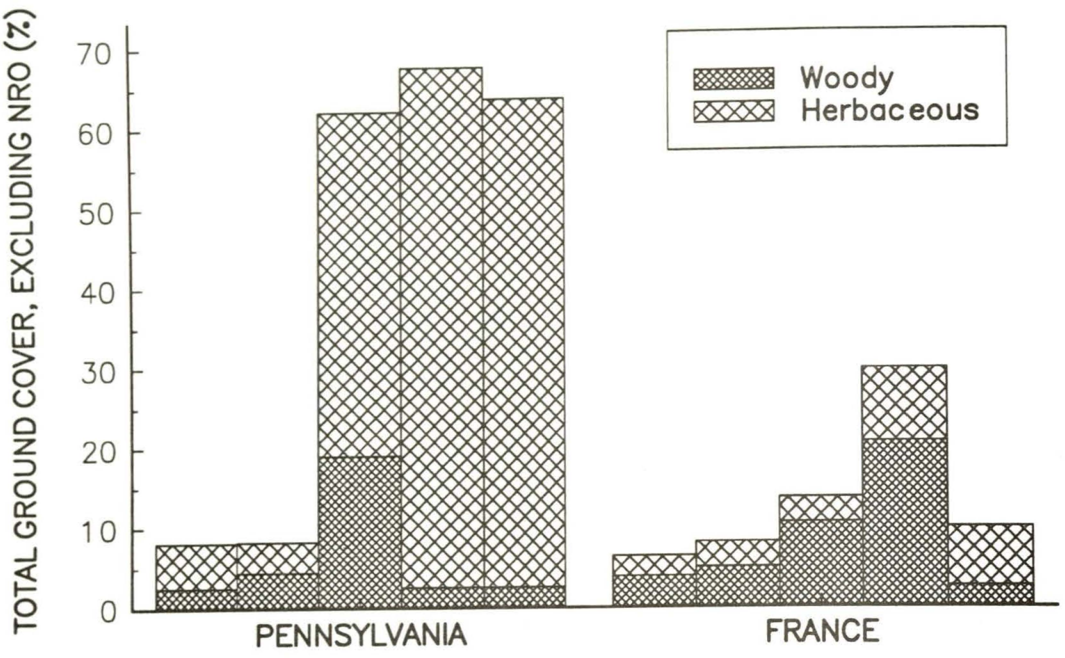


Figure 3. — Distribution of stem heights *versus* age for advance reproduction in PA and FR. PA stem ages were transformed to "age + 0.5" so that PA and FR symbols would not overlap on the plot.

The age-class distribution of seedlings in PA suggests rapid mortality with age. This tends to support the conclusion of Olson and Boyce (1971) that NRO does not persist as advance reproduction more than a few years. Similarly, Clark and Watt (1971) reported that all oak reproduction (species not indicated) died in a 70-year-old stand with overstory density of 23 m^2/ha, but that advance reproduction was able to accumulate under an overstory of 18 m^2/ha. However, the surveyed FR stands accumulated abundant advance reproduction under overstory densities of 21-33 m^2/ha. Significant mortality appeared to be delayed until at least after the fourth growing season in FR, and FR plantations were continuing to recruit seedlings under the additional shade of the almost continuous understory canopy. We think it is more likely that deer browsing, rather than overstory shade, was the most significant factor in seedling mortality over time in PA.

Scholz (1952) suggested that NRO is more shade tolerant than normally believed, and that it is sufficiently tolerant and aggressive to occupy any natural openings where overhead light is available. The development of advance reproduction in FR stands certainly supports that judgment. NRO in these French stands is capable of persisting for several years under high (but unquantified) levels of shade at ground level. Frequent mild thinnings appear to have permitted some stems to persist even longer and accumulate appreciable growth. This class of "dominant" advance reproduction has effectively excluded most potentially competing vegetation.

LITERATURE CITED

Abrams, M.D. 1986. Historical development of gallery forests in northeast Kansas. Vegetatio 65: 29-37.

Abrams, M.D. and J.A. Downs. 1990. Successional replacement of old-growth white oak by mixed-mesophytic hardwood species in southwestern Pennsylvania. Can. J. For. Res. 20: 1864-1870.

Adams, D.E. and R.C. Anderson. 1980. Species response to a moisture gradient in central Illinois forests. Amer. J. Bot. 67: 381-392.

Beck, D.E. 1970. The effects of competition on survival and height growth of red oak seedlings. USDA Forest Service Res. Pap. SE-56, 7 pp.

Braun, E.L. 1950. Deciduous forests of eastern North America. Macmillan Publishing Co., New York. 596 pp.

Bromley, S.W. 1935. The original forest types of southern New England. Ecol. Monogr. 5: 61-89.

Clark, F.B. and R.F. Watt. 1971. Silvicultural methods for regenerating oaks. IN, Oak Symposium Proceedings, USDA Forest Serv., Northeastern Forest Experiment Station, pp. 37-43.

Clements, F.E. 1936. Nature and structure of the climax. J. Ecol. 4: 252-284.

Crow, T.R. 1988. Reproductive mode and mechanism for self replacement of northern red oak (*Quercus rubra*) — A review. For. Sci. 34: 19-40.

Dawson, J.O., J. McCarthy, J.A. Roush, and D.M. Stenger. 1989. Oak regeneration by clearcutting after a series of partial cuts. USDA Forest Service Gen. Tech. Rep. NC-132, pp. 181-184.

Good, N.F. and R.E. Good. 1972. Population dynamics of tree seedlings and saplings in a mature eastern hardwood forest. Bull. Torrey Bot. Club 99: 172-178.

Host, G.E., K.S. Pregitzer, C.W. Ramm, J.B. Hart, and D.T. Cleland. 1987. Landform-mediated differences in successional pathways among upland forest ecosystems in northwestern Lower Michigan. For. Sci. 33: 445-457.

Johnson, P.S., R.D. Jacobs, A.J. Martin, and E.D. Godel. 1989. Regenerating northern red oak: three successful case histories. North. J. Appl. For. 6: 174-178.

Kittredge, D.B., Jr., and P.M.S. Ashton. 1990. Natural regeneration patterns in even-aged mixed stands in southern New England. North. J. Appl. For. 7: 163-168.

Kolb, T.E., T.W. Bowersox, L.H. McCormick, and K.C. Steiner. 1989. Effects of shade and herbaceous vegetation on first-year germination and growth of direct-seeded northern red oak, white ash, white pine, and yellow-poplar. USDA Forest Service Gen. Tech. Rep. NC-132, pp. 156-161.

Korstian, C.F. 1927. Factors controlling germination and early survival in oaks. Yale University School of Forestry, Bulletin No. 19, 115 pp.

Kucera, C.L. 1959. Weathering characteristics of deciduous leaf litter. Ecology 40: 485-487.

Lanier, L., R. Keller, and A. Kremer. 1980. Le chene rouge (*Quercus rubra* L.) en France. Revue Forestiere Francaise 32: 419-451.

Loftis, D.L. 1988. Regenerating oaks on high-quality sites, an update. In, H.C. Smith, A.W. Perkey, and W.E. Kidd, Jr. (eds.), Guidelines for Regenerating Appalachian Hardwood Stands, West Virginia University Books, Morgantown, pp. 199-209.

Loftis, D.L. 1990. Predicting post-harvest performance of advance red oak reproduction in the southern Appalachians. For. Sci. 36: 908-916.

Lorimer, C.G. 1984. Development of the red maple understory in northeastern oak forests. For. Sci. 30: 3-22.

McClaugherty, C.A., J. Pastor, J.D. Aber, and J.M. Melillo. 1985. Forest litter decomposition in relation to soil N dynamics and litter quality. Ecology 66: 266-275.

Michaux, F.A. 1853. North American Sylvan, Vol. 1. Robert P. Smith Publishing, Philadelphia. 123 pp.

Minckler, L.S. and C.E. Jensen. 1959. Reproduction of upland central hardwoods as affected by cutting, topography, and litter depth. J. For. 57: 424-428.

Nowacki, G.J., M.D. Abrams, and C.G. Lorimer. 1990. Composition, structure and historical development of northern red oak stands along an edaphic gradient in north-central Wisconsin. For. Sci. 36: 276-292.

Nowacki, G.J. and M.D. Abrams. 1991. Community and edaphic analysis of mixed oak forests in the ridge and valley province of central Pennsylvania. Proc. Central Hardwood Forest Conf. 8: 247-260.

Olson, D.F., Jr., and S.G. Boyce. 1971. Factors affecting acorn production and germination and early growth of seedlings and seedling sprouts. In, Oak Symposium Proceedings, USDA Forest Serv., Northeastern Forest Experiment Station, pp. 44-48.

Pallardy, S.G., T.A. Nigh, and H.E. Garrett. 1988. Changes in forest composition in central Missouri: 1968-1982. Am. Midl. Nat. 120: 380-390.

Sander, I.L. 1971. Height growth of new oak sprouts depends on size of advance reproduction. J. For. 69: 809-811.

Sander, I.L. 1972. Size of oak advance reproduction: key to growth following harvest cutting. USDA Forest Service Res. Pap. NC-79, 6 pp.

Sander, I.L., P.S. Johnson, and R. Rogers. 1984. Evaluating oak advance reproduction in the Missouri Ozarks. USDA Forest Service Res. Pap. NC-251, 16 pp.

Sander, I.L. 1990. *Quercus rubra* L. Northern red oak. In, Silvics of North America, Vol. II, Hardwoods, USDA Forest Service Agric. Handbk. 654, pp. 727-733.

Schnur, G.L. 1937. Yield, stand, and volume tables for even-aged upland oak forests. USDA Tech. Bull. 560, 88 pp.

Scholz, H.F. 1952. Age variability of northern red oak in the Upper Mississippi woodlands. J. For. 50: 518-521.

Scholz, H.F. 1955. Growth of northern red oak seedlings under variable conditions of ground cover competition. USDA Forest Serv. Tech. Note LS-430, 2 pp.

Smith, L.L. and J.L. Vankat. 1991. Communities and tree seedling distribution in Quercus rubra- and Prunus serotina-dominated forests in southwestern Pennsylvania. Am. Midl. Nat. 126: 294-307.

Tryon, E.H. and K.L. Carvell. 1958. Regeneration under oak stands. West Virginia Univ. Agric. Exper. Sta. Bull. 424T, 22 pp.

Tryon, E.H. and K.L. Carvell. 1962. Comparison of acorn production and damage on sites with abundant and with sparse oak regeneration. West Virginia Univrsity Agricultural Experiment Station, Current Report 36, 7 pp.

The Effects of Gypsy Moth Defoliation on Soil Water Chemistry[1]

Thomas R. Eagle, Jr. and Ray R. Hicks, Jr.[2]

Abstract: Twenty-eight plots were established in oak stands along the leading edge of gypsy moth migration into north-central West Virginia. Plots were arranged in a 3-chain square grid pattern in areas of varying aspect, percent slope, elevation, site index and species composition. Soil water, gypsy moth frass and leaf fragments generated by larval feeding were collected weekly from May 14 until July 30, 1992. Frass and leaf fragments were sorted and weighed. Water and frass samples were analyzed to determine concentrations of sodium, potassium, magnesium, calcium, hydrogen, phosphate and nitrate. Estimates of average defoliation were also made for each plot on a weekly basis.

The objectives of this study are;

- To determine the effects of gypsy moth defoliation on soil water chemistry.
- To correlate frass deposition and litter fall with changes in soil water chemistry.
- To create a baseline of data from which inferences or predictions can be made about the effects of gypsy moth defoliation on stream water chemistry.

To date, only preliminary analyses have been performed. Element concentrations for the water samples were weighted by the volume of water collected. Frass and leaf fragment weights were converted to per acre values. Data from all twenty-eight plots were combined and weekly means were calculated.

Element concentrations over time show possible trends. The deposition of frass and leaf fragments was greatest during the seventh week (June 25) of the twelve week sample period. The concentration of phosphate in the water samples also peaked during this week. Potassium, nitrate and calcium all showed similar trends. Their concentrations initially decreased until the fourth or fifth week (June 4 and 11) then increased until reaching a maximum at or near the eighth week (July 2). Unlike phosphate, potassium and nitrate concentrations were greatest during the eighth week rather than the seventh week when gypsy moth feeding seemed to be at its greatest. This may be attributed to a lag effect. Concentrations of sodium and magnesium showed a steady decrease throughout the defoliation period with only minor increases during peak frass and leaf fragment deposition. Levels of pH showed very little variation throughout the sample period.

---

[1] This work was performed at the West Virginia University Forest and is partially funded by the USDA Forest Service, Northeast Forest Experiment Station, Morgantown, WV.

[2] The authors are Graduate Assistant and Professor of Forestry, West Virginia University, Morgantown WV.

Selected Soil Enzyme Activities in an Oak-Hickory Forest Following Long-Term Prescribed Burning

M.R. Bayan and F. Eivazi[1]

INTRODUCTION

The biochemical reactions within the soil are mediated by soil flora and fauna, and are catalyzed by enzymes. Therefore, enzymes play a significant role in nutrient cycling. Enzymes are specific for the type of chemical reactions in which they participate. Arylsulfatase is the enzyme that catalyzes the hydrolysis of an arylsulfate anion by fission of the oxygen-sulfur (0-5) bond. α-Glucosidase catalyzes the hydrolysis of α-D-glucopyranosides and is involved in the hydrolysis of maltose. β-Glucosidase catalyzes the hydrolysis of β-D-glucopyranosides and is involved in the hydrolysis of cellobiose. The hydrolysis products of glycosidases are believed to be an important energy source for microorganisms in soils (Tabatabai, 1982). Acid phosphatase mediates the release of inorganic phosphorus (P) from organically-bound P returned to the soil as litter and other organic debris. Urease catalyzes the hydrolysis of urea to carbon dioxide and ammonia. It acts on carbon-nitrogen (C-N) bonds other than the peptide linkage. Urease is important in organic N mineralization (Tabatabai, 1982).

Although the effect of prescribed burning on nutrient availability and cycling in forest soils has been investigated by many workers (Wells, 1971; Stark, 1973; Vance and Henderson, 1984; Weetman et al., 1990; Marion et al., 1991) little is known about the effect of fire on the activities of important soil enzymes. The objective of this study was to evaluate the effect of long-term burning on the activities of arylsulfatase, acid phosphatase, α- and β-glucosidases, and urease.

MATERIALS AND METHODS

Soil samples were collected from a long-term burning experiment in southeastern Missouri. Even-aged stands of post oak (*Quercus stellata*), black oak (*Quercus velutina*), southern red oak (*Quercus falcata*), scarlet oak (*Quercus coccinea*), and hickory (*Carya* spp.) occupy the site. The burning experiment was established in 1949. The experiment consists of three treatments: (1) "annual burning", (2) "periodic burning" (every four years), and (3) "control". The soil is classified as a Typic Fragiudalf. Samples were collected in May 1992, a month after the "annual burning" treatment. Each plot was divided into 16 equally spaced areas and the soil was sampled (top 15cm) after removing the O_1 horizon. Samples for each plot were mixed and stored in plastic bags at 5 °C.

Acid phosphatase activity was determined using a method developed by Eivazi and Tabatabai (1977). The method of Tabatabai and Bremner (1970) was used for assaying arylsulfatase activity. α- and β-Glucosidase activities were determined by the method of Tabatabai (1982). These standard procedures involve colorimetric determination of *p*-nitrophenol released when soil is incubated with toluene and the respective buffered substrates for one hour at 37 °C. The urease activity was determined by a method described by Tabatabai and Bremner (1972). This method involves estimation of the ammonium (NH_4^+) released on incubation of toluene-treated soil with buffered urea solution.

---

[1] Post-doctorate fellow, The School of Natural Resources, University of Missouri-Columbia; and Associate Professor, Department of Agriculture, Lincoln University, Jefferson City, Missouri.

An analysis of variance of the data was made, and Duncan's Multiple Range Test was used for comparing means at 5% probability level.

RESULTS

Burning treatments, annual and periodic, did not affect the pH, organic C content, and β-glucosidase activity (Table 1). The activity of α-glucosidase, on the other hand, was reduced significantly by burning treatments, with annual burn showing a marked reduction of the activity of this enzyme. Acid phosphatase activity was also significantly reduced by burning treatments. The effect of "annual burning" on the activity of this enzyme was more pronounced than the "periodic burning". Sulfatase and urease activities were not affected by "periodic burning". "Annual burning", however, significantly reduced the activity of these enzymes (Table 1).

In summary, this experiment indicates that burning the forest floor debris reduces the rate of biochemical reactions by reducing the activities of most soil enzymes. Therefore, phosphorus, nitrogen, sulfur, and carbon dynamics within the forested ecosystem are significantly affected by burning. The effect of "periodic burning" on enzyme activities is generally less severe but, nonetheless, significant.

REFERENCES

Eivazi, F. and M. A. Tabatabai, 1977. Phosphatases in soils. Soil Biol. Biochem. 9:167-I72.

Marion, G. M, J.M., Moreno and W. C. Oechel, 1991. Fire severity, ash deposition, and clipping effects on soil nutrients in chaparral. Soil Sci. Soc. Am. J. 55:235-240.

Stark, N., 1973. Nutrient cycling in a Jeffrey pine forest ecosystem. University of Montana Press. Missoula, Montana. 389 p.

Tabatabai, M. A. and J. M. Bremner, 1970. Arylsulfatase activity of soils. Soil Sci. Soc. Am. Proc. 34:225-229.

Tabatabai, M.A., and J.M. Bremner, 1972. Assay of urease activity in soils. Soil. Biol. Biochem. 4:479-487.

Tabatabai, M.A., 1982. Soil Enzymes. p. 903-943. In (Page, A.L., ed.) Methods of soil analysis. Number 9 (part 2) American Society of Agronomy, Madison, Wisconsin.

Vance, E. D., and G. S. Henderson, 1984. Soil nitrogen availability following long-term burning in an oak-hickory forest. Soil Sci. Soc. Am. J. 48:184-190.

Wells, C.G., 1971. Effects of prescribed burning on soil chemical properties and nutrient availability. p. 86-97. In prescribed Burning Symposium Proc. USDA For. Serv. Gen. Tech. Rep. WO-7, 340 p.

Weetman, G. F., R. Fournier, E. Schnorbus Panozzo, and J. Berk., 1990. Post-burn nitrogen and phosphorus availability of deep humus soils in coastal British Columbia cedar, hemlock forests and the use of fertilization and salal eradication to restore productivity. In (Gessel et al., eds.) Sustained productivity of forest soils. Proc. of the 7th North Amer. For. Soils Conf. July 1988. p. 471-499.

Table 1.—Effect of long-term prescribed burning on selected enzyme activities

Treatment	**pH**	**Organic-C(%)**	**acid phos***	**α-glu***	**β-glu***	**sulfatase***	**urease†**
Control	4.8a††	1.0a	125a	12.4a	33.5a	66.8a	255a
Annual burn	4.8a	0.9a	96c	9.6b	32.6a	55.4b	170b
Periodic burn	4.7a	1.0a	117b	10.4b	31.0a	58.0b	238a

* μg*p*-Nitrophenol released g^{-1} soil hr^{-1} at 37 °C. Phos=phosphatase; Glu=glucosidase.
† μg Ammonium N released g^{-1} soil/2 hr.
†† Means within each column followed by the same letter are not significantly different ($P \leq 0.05$) by Duncan's Multiple Range Test.

Management and Prediction of Red Oak Decline in the Missouri Ozarks

James J. Wetteroff and John P. Dwyer[1]

Abstract: In 1990, 72, 0.50-acre permanent plots were laid out and tree and regeneration data was collected on four sites which showed evidence of red oak decline in the Missouri Ozarks. In the fall of 1990, three treatments were applied; a control, selection cutting, and clearcutting.

Using logistic regression, probability of individual tree survival was modelled for black and scarlet oaks. Using dendrochronology, the effect of decline on tree growth was examined.

Results showed that increased competition decreased tree survival. Also, increased tree age and soil depth increased tree survival. An important finding was that red oak growth rates were related to level of visible crown dieback.

---

[1] School of Natural Resources, University of Missouri, Columbia, MO, 65211.

An Assessment of Advance Regeneration and Herbaceous Communities in Pennsylvania Forests

W.H. McWilliams[1], S.L. Stout, T.W. Bowersox, and L.H. McCormick

Abstract: Intensive research in several parts of Pennsylvania has demonstrated that dense herbaceous cover can inhibit the development of advance regeneration, and that advance regeneration often is lacking in Pennsylvania forests. The lack of quantitative statewide information on forest understory prompted a study to characterize advance regeneration and fern inhibition for Pennsylvania's forests. The study's primary objectives are to:

1) Assess the status and character of advance regeneration.
2) Evaluate the abundance and occurrence of fern.
3) Estimate the extent and abundance of deer food.
4) Correlate composition of understory with overstory vegetation.

Data used in the study were collected by the USDA Forest Service, Northeastern Forest Experiment Station, Forest Inventory and Analysis (NE-FIA) project. Measurements of competing vegetation and seedling regeneration were added to the standard set of NE-FIA measurement variables. Collection techniques were designed to augment existing understory measurements and minimize collection time, and were based on research procedures developed and tested in research studies conducted in Allegheny hardwood and oak forests by Marquis and others. Data were collected during the growing season as the NE-FIA inventory progressed through Pennsylvania.

The analysis of results is in an initial phase intended to evaluate the extent to which NE-FIA measurements can be used to address the study's objectives. The first step was to compile a database containing variables routinely computed by NE-FIA paired with a supplemental set of plot- and county-level attributes. Next, a search will be conducted for relationships between advance regeneration and other parameters such as forest type, stand density, disturbance history, and deer populations. The potential of using the data for spatial analyses also will be examined. This poster describes the regeneration issue in Pennsylvania and presents procedures, plot distribution, and initial results of the study.

---

[1] W.H. McWilliams is Research Forester, Forest Inventory and Analysis, USDA Forest Service, Northeastern Forest Experiment Station, Radnor, PA. S.L. Stout is Project Leader, Silvicultural Decision Systems for Eastern Hardwood Forests of the Mid-Atlantic Region, USDA Forest Service, Northeastern Forest Experiment Station, Warren, PA. T.W. Bowersox and L.H. McCormick are, respectively, Professor and Associate Professor, School of Forest Resources, Pennsylvania State University, University Park, PA.

Characterizing Forest Composition of the Allegheny Mountains Using Extensive Forest Inventory Data

W.H. McWilliams, R. Riemann Hershey, D.A. Drake, and C.L. Alerich[1]

Abstract: There is a general lack of information that describes forest composition at the landscape level, e.g. for entire physiographic provinces. Studies in the ecological literature usually are local in scope and combining data from such studies is questionable due to different design methodology. The USDA Forest Service conducts extensive forest inventories, but the data are typically reported according to political boundaries (counties), have limited ecological scope, and include collapsed forest cover classifications. The Northeastern Forest Experiment Station, Forest Inventory and Analysis (NE-FIA) project is developing a system that addresses these limitations by using extensive forest inventory data in a new way. A prototype of the system is being tested on forests of the Allegheny Mountains of Pennsylvania, Maryland, and West Virginia. The approach combines Geographic Information Systems (GIS) and Relational Database Management Systems (RDMS) technology. The GIS serves three purposes: 1)compiles spatial information for all land uses, 2)extracts NE-FIA data for the study region, and 3)produces maps displaying study results. As the system develops further, the GIS will prove to be a valuable tool for quantifying more complex topological relationships. The RDMS stores extensive inventory data for individual trees and plots measured by NE-FIA on forest land. Once extracted, the inventory data are used to characterize forest composition. For example, a variety of importance values and diversity measures can be computed and then used to describe the region's forests in terms of major association, slope, aspect, terrain position, drainage class, disturbance history, and other variables. This poster depicts initial results of using the prototype for the Allegheny Mountains.

---

[1] W.H. McWilliams, R. Riemann Hershey, D.A. Drake, and C.L. Alerich are Foresters, Forest Inventory and Analysis, USDA Forest Service, Northeastern Forest Experiment Station, Radnor, PA.

Development of an Ecological Classification System for the Wayne National Forest[1]

David M. Hix and Andrea M. Chech[2]

Abstract: In 1991, a collaborative research project was initiated to create an ecological classification system for the Wayne National Forest of southeastern Ohio. The work focuses on the ecological land type (ELT) level of ecosystem classification. The most common ELTs are being identified and described using information from intensive field sampling and multivariate data analyses. The tentative ELT classification developed as a first approximation for Athens Unit (about one third of the entire forest) includes 17 ecological units defined by their slope position, steepness, aspect, and landform. A total of 62 relatively undisturbed, mature (> 70 years old) forest ecosystems have been sampled. Most ELTs are dominated by mixed forests of white oak (*Quercus alba* L.), northern red oak (*Q. rubra* L.), black oak (*Q. velutina* Lam.), shagbark hickory (*Carya ovata* (Mill.) K. Koch), sugar maple (*Acer saccharum* Marsh.), and yellow—poplar (*Liriodendron tulipifera* L.). Two of the ELTs are bottomland units. Ultimately, the functional relationships between climate, geology, physiography, soils, and vegetation (both herbaceous and woody) on all three units of the national forest will be separately and quantitatively investigated.

INTRODUCTION

The majority of Ohio's forestland is found in the southeastern part of the state. In this region, the dominant tree species are oaks, hickories, yellow-poplar, and maples. These forests are a very valuable natural resource. For instance, oak acorns are an extremely important food item for white-tail deer, wild turkey, and many other animal and bird species. These forests are also utilized by many recreational users, including hunters, bird watchers, and other outdoor enthusiasts.

A large proportion (42%) of the forest stands in southeastern Ohio are mature (Redett et al. 1982). It is becoming increasingly important for the stewards of these forests to base their management decisions on an ecosystem perspective (Brooks and Grant 1992). Research in the problem area of ecosystem classification and analysis is considered a high priority (Buckman and Loftus 1985, Sesco 1990, Gordon 1990). It is important to begin the necessary research to provide this information since only very limited research related to this subject has been accomplished.

On June 1, 1991, a collaborative project was initiated to create an ecological classification system for the Wayne National Forest of southeastern Ohio. The purpose is to identify the major forested ecological land types (ELTs) of southeastern Ohio. These ELTS will be assemblages of landscape ecosystems (Barnes et al. 1982, Barnes 1986) that are similar in physiography (landform), soil, and vegetation. These ELTs also have similar silvicultural potential, such as choices of species and cultural practices, and they have predictable pathways or patterns of early successional dynamics (Host et al. 1987, Hix and Lorimer 1991). Multi-factor ecological classification systems have been developed for other nearby regions (e.g., Cleland et al. 1985, Hix 1988, Archambault and Barnes 1990).

---

[1] This research was supported by funds provided by the USDA Forest Service, Northeastern Forest Experiment Station; and by the Ohio Agricultural Research and Development Center, The Ohio State University.

[2] Assistant Professor and Research Assistant, respectively, School of Natural Resources, The Ohio State University, Columbus, OH 43210.

STUDY AREA

The Wayne National Forest is located in southeastern Ohio (Figure 1). It lies within the Unglaciated Allegheny Plateau physiographic region (Fenneman 1938). The landscape is a strongly dissected upland, characterized by hilly terrain, steep winding valleys, and outcroppings of bedrock. Because of the differences in terrain compared with the glaciated portion of the state, this distinct region is often called the "Hill Country" (Lafferty 1979).

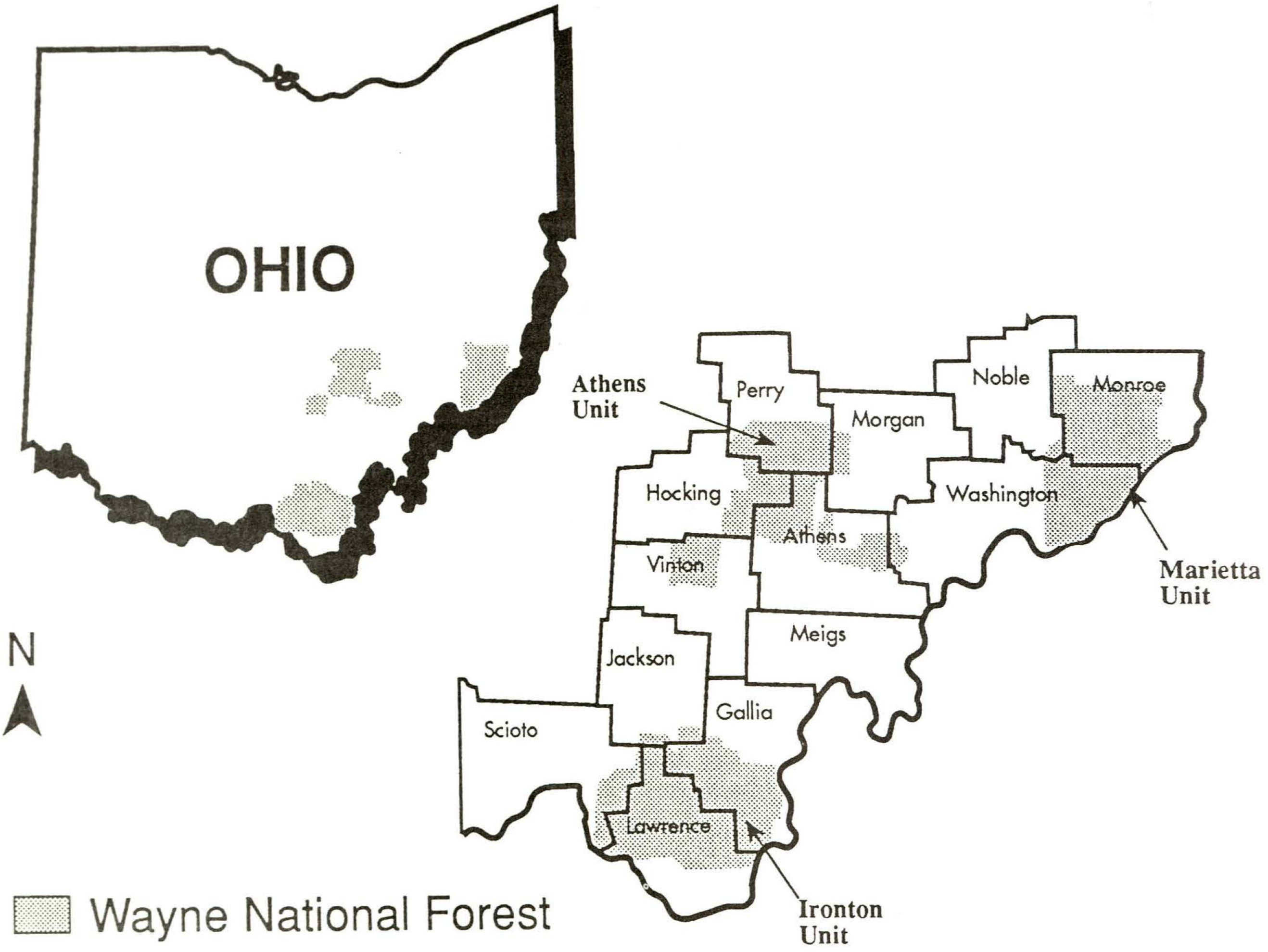

OHIO
Athens Unit
Perry
Noble
Monroe
Morgan
Hocking
Washington
Athens
Vinton
Marietta Unit
Meigs
Jackson
Gallia
Scioto
Lawrence
Ironton Unit
N
▨ Wayne National Forest

Figure 1.—The Wayne National Forest presently includes 205,000 acres in three units.

Most stands in southeastern Ohio are not the presettlement forests, i.e., they have been harvested one or more times since settlement by European immigrants in the 1800s (Gordon 1969). The history and management of many stands are known since the 1940s (Kincaid 1982). Many stands are of sprout-origin, having been established after clearcutting approximately 80-120 years ago (Ducey 1982). The area is part of the mixed mesophytic forest region delineated by Braun (1950). Gordon (1969) describes the original vegetation types of the area as mixed oak, mixed mesophytic, and beech forests. Presently, the two major forest type groups are oak-hickory and Appalachian mixed hardwoods (cove hardwoods). Appalachian mixed hardwoods includes the Society of American Foresters' cover types of yellow-poplar-white oak-northern red oak and yellow—poplar, while oak-hickory includes white oak-black oak-northern red oak, white oak, and black oak (Eyre 1980).

METHODS

The development of the ecological classification system (ECS) will be an iterative process composed of several steps in a repetitive sequence (Figure 2). Reconnaissance is not only done in the field; much useful information is available from the literature and from published maps and reports. Sampling is necessary during several field seasons to develop the several approximations of the

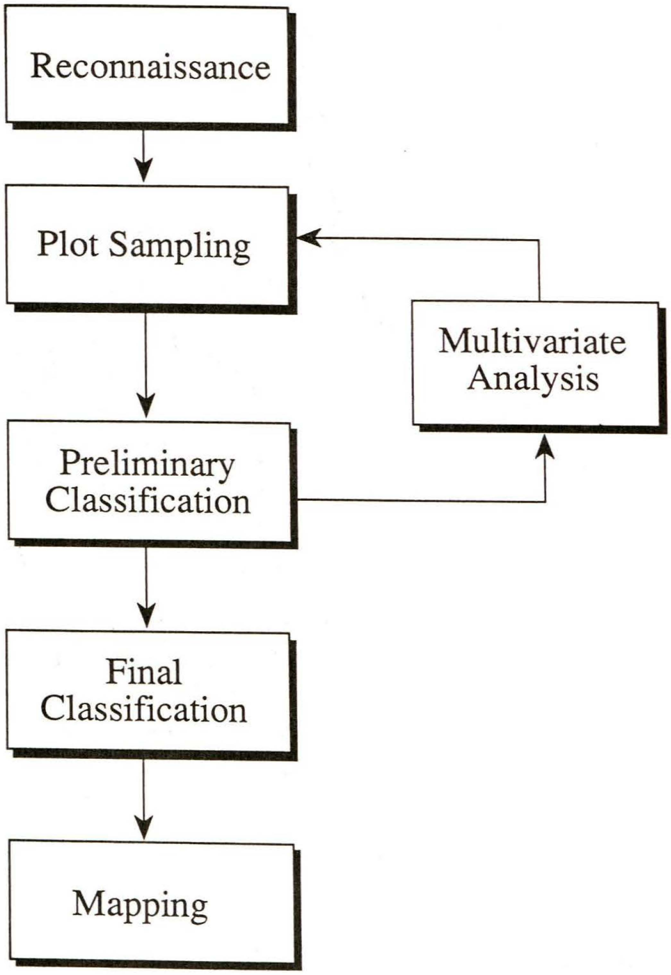


Figure 2.—Model of the system being used to develop the ecological classification system.

classification. Multivariate analyses will be used to corroborate the ECS. Finally, field mapping will be a possibility once the final classification has been developed.

A tentative ecological land type classification (Table 1) was used as the basis for stratifying the sampling during this first field season. This system is based primarily on physiography. The factors that are integrated include landform, slope of the terrain, aspect, and slope position. Most of the ELTs are uplands, but two types of bottomland ELTs were also proposed. Within this system, we also carefully consider the soil type, i.e., loess, colluvium, etc., and the interrelationships between physiography and soils. Relationships between the vegetation and the physiography and soils will be then studied. Old road maps and aerial photographs are often checked to determine the past use and history of an area.

The following criteria were used for identifying acceptable areas for sampling:

(1) living trees (> 10 cm dbh) are mature (at least 70 years old);
(2) no evidence of major disturbance by human beings within the last ,40 years (e.g., no stumps in plot, no underplanting);
(3) a minimum size of 0.4 ha (1.0 acre);
(4) a general absence of early successional species;
(5) no evidence of recent fire, windthrow, or unexplainable mortality;
(6) stand is "fully stocked";
(7) no extensive (multiple-tree) gaps in the canopy; and
(8) area is not an old field or old—pasture.

These criteria are similar to those being used to develop an ecological classification system for the Hoosier National Forest of southern Indiana
(Van Kley and Parker 1991).

Sampling Design

The USDA Forest Service database (Vegetative Management Information System) was searched for potential field sites, and lists of stands meeting the minimum criteria for stand age were created. Reconnaissance in the field permits the selection of areas apparently suitable for sampling. Cultural resource surveys are completed on these stands by the Forest Service before sampling.

Locations for sampling were randomly selected from the pool of qualified stands in the VMIS database. The goal was to select at least four areas for sampling from each type or stratum in the tentative Ecological Land Type classification system (Table 1). Within each representative stand, at least two sample plots were located.

First, a sketch map was drawn of each homogeneous area within a stand to be sampled. On this drawing, lines were added that divided each area into two parts approximately equal in size. These lines were the longest lines possible across the area parallel to the slope. The first plot was located at least 20 m from the start of the transect line; subsequent plots were located at least 30 m apart.

Table 1.—Tentative Ecological Land Type classification system and sample size for each tentative ELT

	Number of homogeneous areas	**Number of plots**
UPLANDS		
Level to gently sloping terrain (0-15%)		
1. Broad summits		
2. Narrow ridgetops	3	8
3. Benches	2	4
Moderately to steeply sloping terrain (16-30%)		
Northerly aspects (316°-135°)		
4. Upper slopes	2	5
5. Middles slopes	2	4
6. Lower slopes	1	2
Southerly aspects (136°-315°)		
7. Upper slopes	3	7
8. Middle slopes	5	10
9. Lower slopes	1	2
Very steeply sloping terrain (> 30%)		
Northerly aspects (316°-135°)		
10. Upper slopes		
11. Middle slopes	2	4
12. Lower slopes		
Southerly aspects (136°-315°)		
13. Upper slopes		
14. Middle slopes	1	2
15. Lower slopes	1	2
BOTTOMLANDS		
16. Narrow coves and ravines	4	8
17. Broad valleys	2	4

A sample "plot" consisted of a set of two nested, concentric, circular sub-plots (sizes = 500 m² and 100 m²), and eight rectangular 1- by-2 m sub-sub-plots or quadrats (Figure 3). The centers of the quadrats were located 2 m beyond the outside edge of the 100 m² sub-plot in each cardinal direction. If a plot center coincided with a tree trunk or other obstruction, the plot center was extended by 2 m.

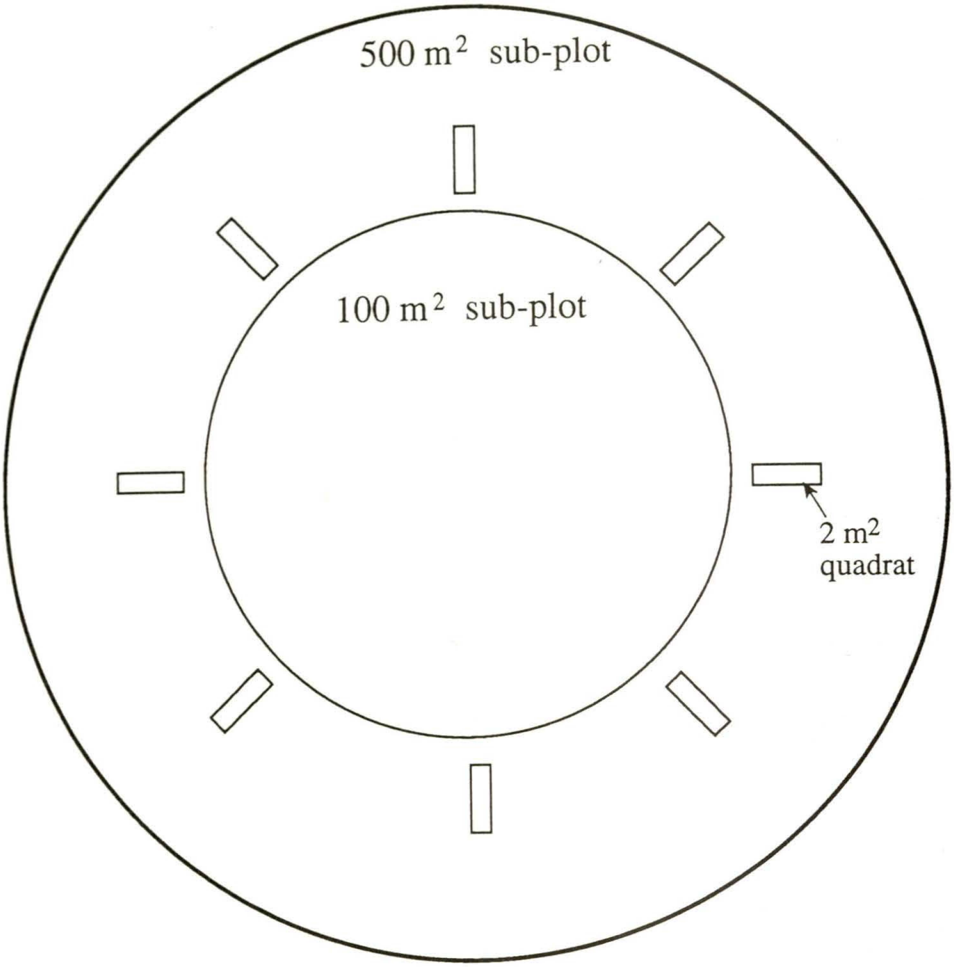


Figure 3.—Plot design being used for sampling of the vegetation.

Vegetation

Woody plants of different sizes were tallied in each plot:

Plot size	**Size of individuals and Procedures**
500 m²	Living trees > 10 cm dbh were tallied by species.
100 m²	Living saplings were tallied by species and dbh class: 0.1-5.0 cm or 5.1-10.0 cm.
2 m²	Living seedlings were tallied by species and height class: 0.1-30.0 cm, 30.1-100.0 cm, or 100.1-136.0 cm. Sprouts upon woody plant stems were not included as separate individual seedlings.

In addition, the ground cover (up to 1 m in height) of seedlings, shrubs, vines, and herbs was sampled by species in each quadrat. The portion of a plant was included in the rating if that portion overhung the boundary, even if the plant was rooted outside the quadrat. Coverage was estimated visually, but a meter stick was used frequently in the estimations. The following cover classification system was used to measure the importance of each species:

Cover class code	Percent coverage
1	< 1
2	1-5
3	6-10
4	11-20
5	21-40
6	41-70
7	71-100

In each sampling unit, a list of the herbaceous species encountered on a random walk through the area, but not present in any of the quadrats on the plots, was compiled. Thus, a species presence list has been provided for the entire homogeneous area. If the occurrence of a particular species seemed to be related to some stand disturbance or other factor (e.g., unusual microenvironment like a rock outcropping), the distance and direction of that plant species from the disturbance was documented on a special form.

Voucher specimens were collected for every new species, species of uncertain identity, and species from unusual habitats, except when collecting would have eliminated a local population. All of the approximately 1000 specimens collected during the 1992 field season are being checked for proper identification as a means for assuring the overall quality of our final species identifications. Approximately 40% of the specimens are of grass or sedge species. The assistant curator of the Miami University Herbarium is cooperating in the verification of species identifications.

Physiography

The landform, percent slope, aspect, slope position, length of slope, distance to any surface water bodies, slope shape, distance from ridge, and nature of the general topography were all observed and (or) measured in the field. The following classes for landform were used: summit or level upland, hillslope, bench, and small protected valley or ravine. The elevation of each plot was estimated from a topographic map. Finally, schematic cross sections of each plot were drawn on the plot form.

Soils

The soils of each plot were examined in detail. First, points were located along the contour, one on each side of plot center at the perimeter of the 100 m^2 plot. Then, a second pair of points were similarly located, one on each side of plot center along an imaginary line running perpendicular to the contour through plot center. At these points, a soil-sampling tube was used to obtain profiles which were described and recorded.

A soil pit was excavated in the first plot of each transect at a point representative of the entire plot. It was dug just outside of the nearest quadrat, with the long axis of the pit parallel to the contour. A full profile description was taken from the uphill face of the pit. Bulk samples were collected and bagged from each horizon. After air-drying, each sample will be analyzed to determine textural class and selected chemical and physical properties. A sample was taken with a bucket auger through the pit floor to determine (if possible) the depth to hard bedrock. If the second or third plot along a transect appeared to be underlain by different soils than the first plot, a pit was also installed there and the soil profile was carefully and fully characterized, and samples were collected.

RESULTS AND DISCUSSION

Sample Size

From early June to mid-September, 22 areas were sampled for a total of 48 plots (Table 1). On an additional 14 plots (two each from 7 areas), only the woody vegetation and the physiography were measured; ground cover and soils will be examined during the next field season.

Climate

The Wayne National Forest is located in three separate geographic areas of southeastern Ohio (Figure 1). The Ironton Unit is found the farthest south of the three units, while the Marietta Unit is the farthest east. An analysis of the differences in macroclimate is yet to be completed. It will be important to determine if any distinct gradients in factors such as precipitation exist within the study area. For this reason, separate classifications will be developed for each unit, unless it is determined that some of the units are similar enough in climate to be grouped together.

Geology, Physiography, and Soils

At present, a total of 23 soil pits have been excavated and described, and soil characterizations have been made for forty-four other plots. The written descriptions have been edited and entered into a computer database.

A USDA Soil Conservation Service soil scientist verified a subset of the soil pits. He explained important soil-landscape relationships, such as the difference between the soils developed in loess, and the majority of the soils which either developed in colluvium or alluvium.

An ODNR Geological Survey Division geologist also has visited some of the soil pits to help us interpret certain aspects of the surficial geology. In general, the bedrock of the Athens and Ironton Units is non-calcareous shales and sandstones, while the Marietta Unit is underlain by calcareous shales and limestones. Some local areas such as ridgetops in the Athens Unit possess calcareous soils, and certain characteristic species have been found at these locations.

Vegetation

The overstory (stems > 10 cm dbh) on forty-six plots has been summarized (Table 2). For this presentation, the ELTs were grouped into four categories: narrow ridgetops, hillslopes with northerly aspects, hillslopes with southerly aspects, and narrow coves and ravines. For each species, the average importance value was computed, by averaging its relative density and relative basal area on plots of each group.

Table 2.—Average importance values for overstory tree species of four groupings of tentative ELTs

Species	**Narrow ridgetops**	**Northerly aspects**	**Southerly aspects**	**Narrow coves and ravines**
Acer rubrum	1.9	3.8	8.0	1.3
A. saccharum		6.9	3.9	9.3
Aesculus octandra	7.1	2.9	0.1	4.0
Carya glabra	2.1	2.0	5.2	1.0
C. ovata	8.9	2.5	1.8	
Fagus grandifolia		2.7	5.4	
Fraxinus americana	1.0	4.1	1.6	4.3
Juglans nigra		4.3		
Liriodendron tulipifera		6.8	5.1	6.8
Quercus alba	18.2	21.8	23.3	50.7
Q. coccinea	18.5	1.1	9.9	
Q. muehlenbergii		7.3		
Q. prinus	16.6	1.5	5.6	
Q. rubra	1.4	12.0	12.3	13.8
Q. velutina	19.2	3.5	9.9	2.8
Ulmus rubra	1.9	5.0	0.6	
Number of plots	8	11	21	6

For all four groups, at least one of the oaks was the most common species (Table 2). White oak dominates the overstory in the narrow coves and ravines. It is also the most common species on hillslopes of both north and south aspects (where all slope positions have been combined). On northerly aspects, northern red oak is a common associate, along with sugar maple. Two species unique in this sample to northerly aspects are chinquapin oak (*Quercus muehlenbergii* Engelm.) and black walnut (*Juglans nigra* L.). On southerly aspects, black oak and scarlet oak (*Quercus coccinea* Muenchh.) are common, as is red maple (*Acer rubrum* L.). Narrow ridgetops are heavily dominated by oaks (black, chestnut (*Quercus prinus* L.), white, and scarlet and shagbark hickory Further analyses of the vegetation, and the inter-relationships of all the major ecosystem components, are in progress.

Data Quality

Quality control and assurance are an important aspect of the project. During autumn, a subsample of the 500- and 100 m^2-plots were independently remeasured to identify errors in species identification, tree measurements, or physiographic data. During in the next field season, a subsample of quadrats will be remeasured to determine the variability in cover estimates.

CONCLUSIONS

This five-year study is scheduled to end in 1995. The ecological classification system for the forest, and those for the three units separately, will be finalized by 1994. Stands on all three units will then be sampled for verification of the classifications. Interpretations and descriptions of the ELTs will be prepared, and Forest Service personnel will be trained in the use of the system.

LITERATURE CITED

Archambault, L., Barnes, B.V. and Witter, J.A. 1990. Landscape ecosystems of disturbed oak forests of southeastern Michigan, U.S.A. Can. J. For. Res. 20: 1570-1582.

Barnes, B.V. 1986. Varieties of experience in classifying and mapping forestland ecosystems. pp. 5-23 in Proc. Symp. on Forestland Classification in Relation to Forest Management. Saulte Ste. Marie, Ontario.

Barnes, B.V., Pregitzer, K.S., Spies, T.A., and Spooner, V.H. 1982. Ecological forest site classification. J. Forestry 80: 493-498.

Braun, E.L. 1950. Deciduous forests of eastern North America. Hafner Publ. Co., New York. 596 pp.

Brooks, D.J., and Grant, G.E. 1992. New approaches to forest management. J. Forestry 90: 25-28.

Buckman, R.E., and Loftus, N.S. 1985. Future research on central hardwoods. pp. 1-3 in Proc. Fifth Central Hardwoods For. Conf. Champaign, IL.

Cleland, D.T., Hart, J.B., Pregitzer, K.S., and Ramm, C.W. 1985. Classifying oak ecosystems for management. pp. 120-134 in Proc. Symp. Challenges in oak management and utilization. Univ. of Wis., Madison.

Ducey, L.J. 1982. Hardwood research in southern Ohio. J. Forestry 80: 488—489.

Eyre, F.H., ed. 1980. Forest cover types of the United States and Canada. Soc. of Amer. For., Washington, DC. 148 pp.

Fenneman, N.M. 1938. Physiography of the eastern United States. McGraw—Hill, New York. 714 pp.

Gordon, J.C. 1990. Forestry research: A mandate for change. Committee on Forestry Research, National Research Council. National Academy Press, Washington, DC. 84 pp.

Gordon, R.B. 1969. The natural vegetation of Ohio in pioneer days. Bull. Ohio Biol. Surv., New Series, Vol. III, No. 2. Ohio State University, Columbus. 113 pp.

Hix, D.M. 1988. Multifactor classification and analysis of upland hardwood forest ecosystems of the Kickapoo River watershed, southwestern Wisconsin. Can. J. For. Res. 18: 1405-1415.

Hix, D.M., and Lorimer, C.G. 1991. Early stand development on former oak sites in southwestern Wisconsin. For. Ecol. Manage. 42: 169-193.

Host, G.E., Pregitzer, K.S., Ramm, C.W., Hart, J.B., and Cleland, D.T. 1987. Landform-mediated differences in successional pathways among upland forest ecosystems in northwestern Lower Michigan. For. Sci. 33:445—457.

Kincaid, D.B. 1982. Wayne National Forest: Model of multiple use. J. Forestry 80: 404-405, 408.

Lafferty, M.B., ed. 1979. Ohio's natural heritage. Ohio Acad. Sci., Columbus. 324 pp.

Redett, R.B., Barnard, J.E., and Dennis, D.F. 1982. Ohio's forests today. Ohio Woodlands 19: 9-12.

Sesco, J.A. 1990. Future hardwood research directions. pp. 129-132 in Proc. of Eighteenth Annual Symp. of the Hardwood Research Council, Memphis, TN.

Van Kley, J.E., and Parker, G.R. 1991. An ecological classification for the central hardwoods region: a first approximation. Bull. Ecol. Soc. Amer. 72: 275.

Early Development of Mixed-species Stands on the Wayne National Forest

Eric R. Norland and Dr. David M. Hix[1]

Abstract: The species compositions of many upland hardwood forests in southeastern Ohio appear to be changing. Since the arrival of settlers, most of the mixed mesophytic forest has been cleared at least once as a result of timber cutting, burning, and agriculture. The compositions of the second-and third-growth forests are shifting toward a smaller component of oaks (*Quercus* spp.) and larger proportions of other species such as red maple (*Acer rubrum*). This study examines the development of existing young stands after clearcutting on the Wayne National Forest. A chronosequence of 5- to 30-year old mixed species stands on upper, south-facing slopes is being examined. The soils formed in residuum and colluvium derived from siltstone, sandstone and shale. Thus far, data has been collected on three sample plots in each of five stands. Total number of stems has generally decreased with age, from 24,255 stems/ha at age 6 to 5162 stems/ha at age 20. The oak proportion of the stems decreased from 25.4 to 7.7 percent over time, and the proportion of dominant/codominant oaks as a proportion of all upper crown stratum stems decreased from 51.6 percent at age 6 to 11.9 percent at age 20. Red maple and mixed commercial hardwoods accounted for 55 percent of all dominant/codominant stems at age 20. Hickories (*Carya* spp.), as a group, were a minor component of the sampled stands throughout the entire chronosequence.

INTRODUCTION

The mixed-oak forest comprises the majority of the forestland in the unglaciated, "Hill Country" of southeastern Ohio (Dennis and Birch 1979). A large proportion (42%) of these stands are mature (Redett et al. 1982), and many will most likely be harvested during the next few decades. Although oaks are a major component of the forest, they often do not regenerate and become established following conventional cutting practices; less-valuable, shade-tolerant species are replacing oaks throughout the region (Johnson 1976, Hilt 1985, Beck and Hooper 1986, Crow 1988, Myers and Buchman 1988, George and Fisher 1989).

Some research on tree regeneration following clearcutting has been conducted in southeastern Ohio. Early studies examined the reproduction present immediately after cutting (Merz and Boyce 1958, Walter 1963); more recently the compositions of medium-sized stands (Heiligmann et al. 1985a, Hilt 1985, Ward and Heiligmann 1990) have been investigated. However, very little is known about the developmental processes occuring during the early stages of stand development.

The objective of the current study is to examine the species composition of existing young stands that regenerated following complete clearcutting, and compare them to mature stands on similar sites.

---

[1] The authors are, respectively, Graduate Student and Assistant Professor, School of Natural Resources, The Ohio State University, 2021 Coffey Road, Columbus, OH 43210. Financial support is being provided by a University Seed Grant award from the Office of Research, and by the Ohio Agricultural Research and Development Center, The Ohio State University.

STUDY AREA

This is an on-going study which is being conducted on the Athens Ranger District of the Wayne National Forest. The district is comprised of land-holdings in five counties (Perry, Hocking, Vinton, Athens and Morgan) located in southeastern Ohio (Figure 1). The Marietta Sub-Unit is not included in this study. Located in the physiographic region known as the Unglaciated Allegheny Plateau (Fenneman 1938), the landscape is characterized by hilly terrain, steep winding valleys and outcroppings of bedrock. The soils, classified as Ultic Hapludalfs, formed in residuum and colluvium derived from siltstone, sandstone and shale (USDA 1989).

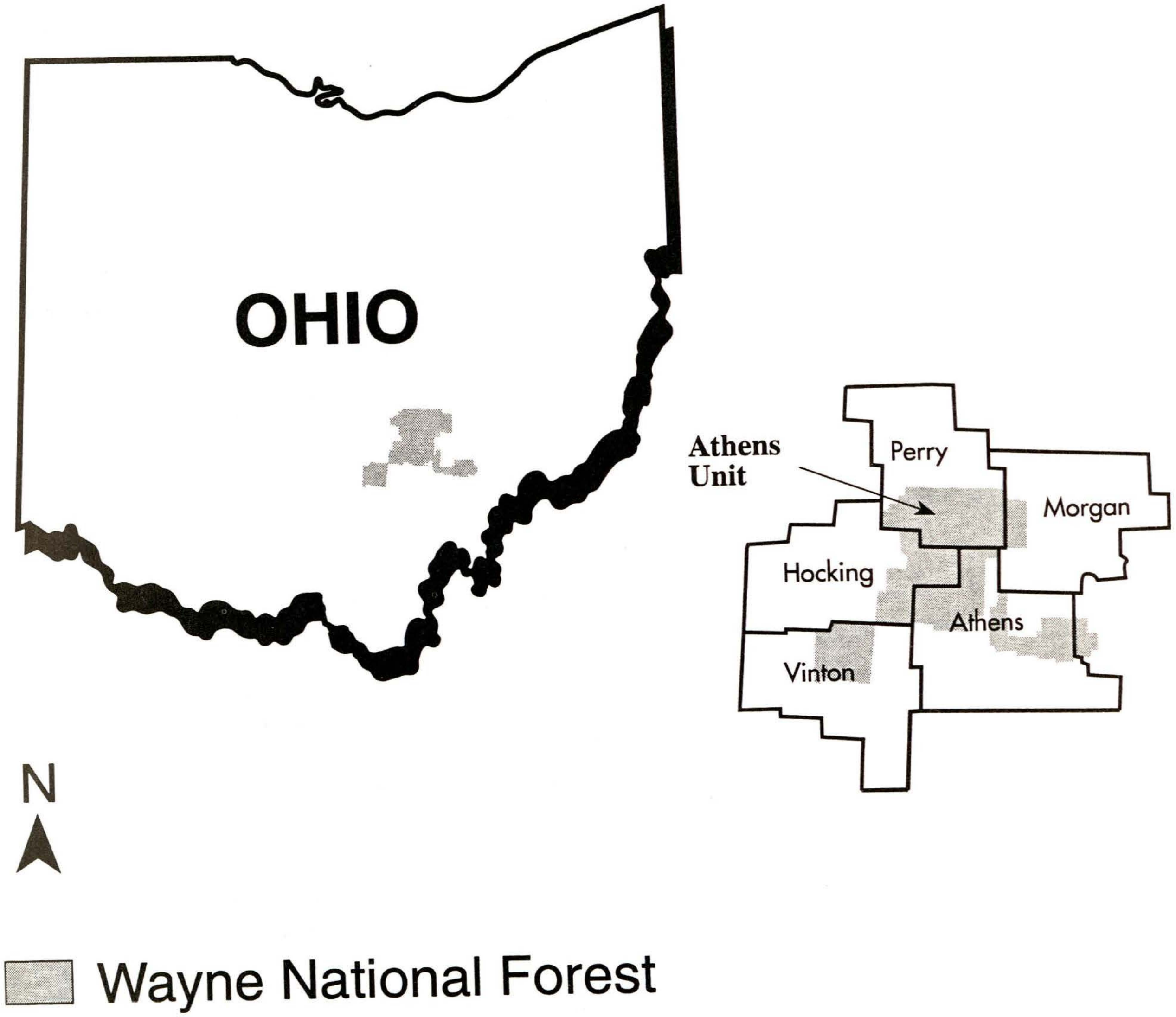


Figure 1.—Location of the Athens Unit, Wayne National Forest.

METHODS

A sequence of stands of different ages (chronosequence) (Oliver 1982) and growing on analogous sites (all one ecosystem unit) (Barnes et al. 1982) is being sampled. Individual ecosystem types or units have predictable pathways or patterns of early successional dynamics (Host et al. 1987, Hix and Lorimer 1991). The ecosystem unit selected for study is mixed-oaks growing on upper south-facing slopes with soils derived from residuum and colluvium.

Even-aged stands that meet the following criteria are being included in the pool from which a sample is being selected:

a. The present stand originated following complete clearcutting.
b. The present stand ranges in total age from 5 to 30 years.
c. The stand is located on a slope with an aspect from 135^{o} - 225^{o}.
d. The soil is derived from residuum and colluvium.
e. No major disturbances have occured since the cutting that established the current stand.

At least three sample plots will be randomly located within each stand. Sampling is being done on circular plots of variable radii, with the plot size increasing with stand age. The species, diameter at 137 cm above the ground (dbh), crown class, and origin (seedling, seedling-sprout, stump-sprout, root-sprout) are being recorded for all living trees greater than or equal to 1.37 m in height. Species and dbh are being recorded for all dead stems. Stand age is being determined from stand history records and by counting the annual rings on disks sawn from the base of the dominant and codominant trees. On each plot, the topographic variables being measured are: aspect, slope, and slope position (relative distance from the bottom of the slope.

Mature, undisturbed stands will be sampled, and their composition will be compared with that of the young, disturbed stands using analysis of variance.

PRELIMINARY RESULTS AND DISCUSSION

Thus far, data has been collected on 15 sample plots ranging in size from 0.003 to 0.027 ha. The results shown in Figure 1 and Tables 1-4 are based on three sample plots in each of five clearcuts of varying ages. Although there is much variability between plots within each stand, some trends are beginning to emerge.

Total number of stems across the choronsequence has generally decreased with stand age, from 24,255 stems/ha at age 6 to 5162 stems/ha at age 20 (Figure 2). The basal area (m^2/ha) has trended upward, but in a much less consistent manner (Table 1).

The pattern is more variable, however, between individual species and species groups. Oaks as a group were a dominant species prior to clearcutting, but by age 20 they are a minor part of the stand composition (Figure 2). Except for the 15-year-old stand, the component of oaks has steadily decreased from 25.4 to 7.7 percent of the total number of stems. When the importance value [(relative density + relative basal area)/2] is considered, the decrease is even more dramatic. At age 6, oaks accounted for about 34 percent of the stand, but by age 20, oaks were the second least important species group (Table 2). This is indicative of one aspect of the oak regeneration problem: oaks which are present early in the development of a stand die for various reasons over time.

Table 1.—Basal area (m^2/ha) of woody stems on complete clearcuts of different ages, by species or species group[1]

	Species/species group							
Age	**Oaks**	**Red maple**	**Yellow-poplar**	**Hickories**	**Mixed comm.**	**Mixed non-comm.**	**Small trees & shrubs**	**Total**
6	3.21	2.38	0.05	0.06	0.55	0.88	0.57	7.70
8	3.94	0.23	0.00	0.95	0.77	3.15	0.25	9.29
14	3.40	2.36	6.72	0.11	6.87	1.94	0.04	21.44
15	2.73	1.60	0.00	0.42	0.53	1.26	0.28	6.82
20	1.98	6.71	3.12	0.21	6.60	1.78	<0.00	20.40

[1] Oaks - *Quercus alba, Quercus coccinea, Quercus prinus, Quercus rubra, Quercus velutina*
Red maple - *Acer rubrum*
Yellow-poplar - *Liriodendron tulipifera*
Hickories - *Carya glabra, Carya tomentosa, Carya cordiformis, Carya ovata, Carya laciniosa*
Mixed commercial - *Fagus grandifolia, Fraxinus americana, Acer saccharum, Juglans nigra, Robinia pseudoacacia, Populus grandidentata, Ulmus rubra, Ulmus americana, Prunus serotina, Nyssa sylvatica*
Mixed non-commercial - *Sassafras albidum, Cornus florida, Ostrya virginiana, Carpinus caroliniana, Oxydendrum arboreum, Cercis canadensis*
Small trees and shrubs - *Corylus americana, Hamamelis virginiana, Rhus glabra, Rhus copallina, Amelanchier arborea, Asimina triloba, Viburnum acerifolium*

Table 2.—Importance values[1] of woody stems on complete clearcuts of different ages, by species or species groups[2]

	Species/species group							
Age	**Oaks**	**Red maple**	**Yellow-poplar**	**Hickories**	**Mixed comm.**	**Mixed non-comm.**	**Small trees & shrubs**	**Total**
6	33.54	28.84	0.93	1.13	7.69	16.52	11.35	100
8	31.20	2.01	0.00	7.33	8.86	45.85	4.75	100
14	13.86	11.00	26.58	1.52	29.42	16.36	1.26	100
15	42.89	16.14	0.00	8.67	8.02	19.25	5.03	100
20	8.69	25.38	13.82	1.86	34.94	15.09	0.22	100

[1] Importance value, $IV = \dfrac{\text{Relative density + relative basal area}}{2}$

[2] Refer to Table 1 for species or species group categories.

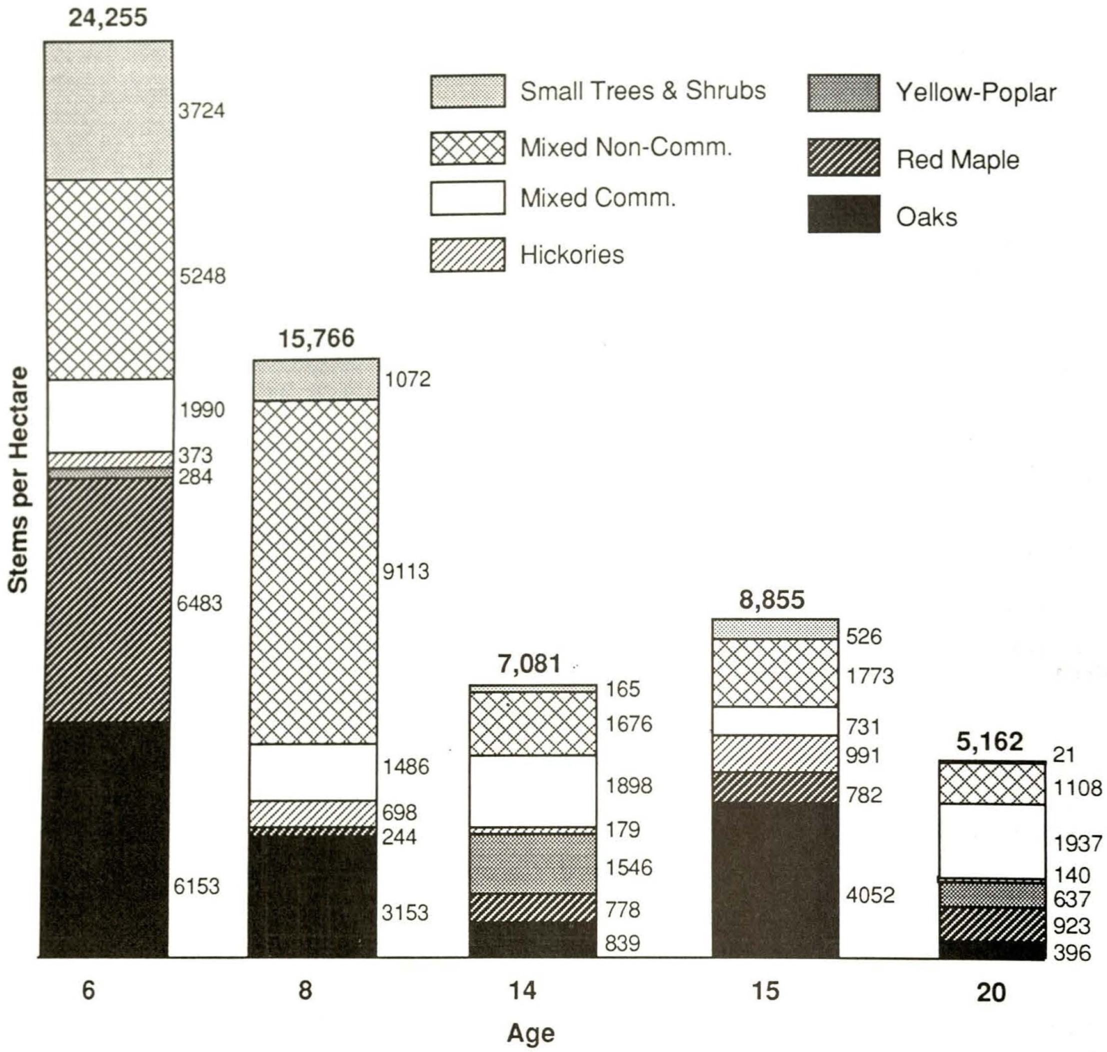


Figure 2.—Number of woody stems (≥1.37 m tall) per hectare on complete clearcuts of different ages, by species or species group categories[2].

There are also changes in the structure of the oak component. The proportion of dominant and codominant oak stems is relatively stable throughout the entire chronosequence, averaging 26.4 percent (Table 3), but the proportion of intermediate stems decreased while the overtopped stems increased. This suggests that, within the oak group, those stems which achieved dominance early in the stand retained it, while many of the intermediate stems eventually became overtopped. However, when viewed as a component of the entire population of dominant stems, the performance of the oaks is poor. At age 6, dominant and codominant oaks accounted for 51.6 percent (1646 stems/ha) of the upper canopy stems, but by age 20, the proportion had decreased markedly, to 11.9 percent (106 stems/ha).

---

[2] Refer to Table 1 for species or species group categories.

Table 3.—Stand structure (stems/ha) of woody stems on complete clearcuts of different ages, by crown class and species or species group[1]

	Stand age				
Species/species group	**6**	**8**	**14**	**15**	**20**
Oaks					
Dominant/Codominant	1646	836	219	1050	106
Intermediate	2331	779	201	861	114
Overtopped	2176	1538	419	2141	396
TOTAL	6153	3153	839	4052	396
Red maple					
Dominant/Codominant	911	142	107	115	257
Intermediate	1945	0	118	299	227
Overtopped	3627	102	553	368	439
TOTAL	6483	244	778	782	923
Yellow-poplar					
Dominant/Codominant	0	0	588	0	230
Intermediate	229	0	396	0	111
Overtopped	55	0	562	0	296
TOTAL	284	0	1546	0	637
Hickories					
Dominant/Codominant	0	222	0	0	0
Intermediate	55	267	11	46	12
Overtopped	318	209	168	945	128
TOTAL	373	698	179	991	140
Mixed commercial					
Dominant/Codominant	476	133	455	43	262
Intermediate	548	357	213	41	289
Overtopped	966	996	1230	647	1386
TOTAL	1990	1486	1898	731	1937
Mixed non-commerical					
Dominant/Codominant	54	364	22	0	37
Intermediate	1311	2529	203	115	33
Overtopped	3883	6220	1451	1658	1038
TOTAL	5248	9113	1676	1773	1108
Small trees and shrubs					
Dominant/Codominant	104	0	0	0	0
Intermediate	1313	209	0	130	0
Overtopped	2307	863	165	396	21
TOTAL	3724	1072	165	526	21

[1] Refer to Table 1 for species or species group categories.

The regionwide trend of increasing red maple dominance on clearcuts (Hilt 1985a) is being observed in this study. At age 6, red maple accounted for 28.8 percent of the total stems and was still present in greater numbers (923 stems/ha) than the oaks (396 stems/ha) at age 20. The importance of red maple in the sampled clearcuts is also evidenced in the upper crown stratum. Twenty years after clearcutting, red maple accounts for more than twice as many dominant and codominant stems as do the oaks (Table 4).

Table 4.—Dominant/codominant stems (stems/ha) for two species/species groups as a proportion of all dominant/codominant stems (stems/ha).

OAKS[1]

Age	Dominant/codominant oak stems	All dominant/codominant stems	Proportion of oak (%)
6	1646	3191	51.6
8	836	1697	49.3
14	219	1391	15.7
15	1050	1208	86.9
20	106	892	11.9

[1] *Quercus alba, Quercus coccinea, Quercus prinus, Quercus rubra, Quercus velutina*

RED MAPLE

Age	Dominant/codominant red maple stems	All dominant/codominant stems	Proportion of red maple (%)
6	911	3191	28.6
8	142	1697	8.4
14	107	1391	7.7
15	115	1208	9.5
20	257	892	28.8

The remainder of the species or species groups have development trends that still appear to be ambiguous, primarily due to the small number of stands sampled so far. The group of non-commercial mixed species (e.g., *Cornus florida, Sassafras albidum,* and *Ostrya virginiana*) has an inconsistent trend. At ages 6 and 8, there were 5248 and 9113 stems/ha respectively. Species such as flowering dogwood and sassafras regenerate in large numbers after clearcutting but are unable to compete with commercial hardwood species over time (Hilt 1985a). In the remainder of the chronosequence (14-20 years) non-commercial species ranged from 20 to 23.7 percent of the total stems/ha.

Hickories, as a group, were a very minor component of the entire chronosequence. Although there was no consistent trend, by age 20 hickory stems only comprised 2.7 percent of the total.

Yellow-poplar was another species inconsistent in its development pattern. A very minor component at age 6 (1.2% of the total stems), it was absent in the 8- and 15-year-old stands that were sampled. At age 20, it comprised a larger component of the stand than all of the oaks combined. The continued presence and role of yellow-poplar in these stands at maturity is uncertain, however. The species is not considered to be a strong competitor on xeric sites such as those sampled; mortality is usually high when stressful growing conditions develop, especially drought (Hilt 1985b).

The remainder of the comercially-valuable species were aggregated in a single group, consisting of such species as sugar maple (*Acer saccharum*), white ash (*Fraxinus americana*), black cherry (*Prunus serotina*), and others. Although this group was a minor component at age 6, it represented the largest category (37.5% of the stems) at age 20. While this is an artificial aggregation of species with different silvical characteristics, it is indicative of the heterogeneous nature of the stand at an early age.

LITERATURE CITED

Barnes, B.V., Pregitzer, K.S., Spies, T.A., and Spooner, V.H. 1982. Ecological forest site classification. J. Forestry 80:493-498.

Beck, D.E., and Hooper, R.M. 1986. Development of a southern Appalachian hardwood stand after clearcutting. South. J. Appl. For. 10:168-172.

Crow, T.R. 1988. Reproductive mode and mechanisms for self-replacement of northern red oak (*Quercus rubra*) - A review. For. Sci. 34:19-40.

Dennis, D.F. and Birch, T.W. 1981. Forest statistics for Ohio - 1979 USDA For. Serv. Resour. Bull. NE-68. 79 p.

Fenneman, N.M. 1938. Physiography of the eastern United States. McGraw-Hill, New York. 714 pp.

George, D.W. and Fischer, B.C. 1989. The effect of site and age on tree regeneration in young upland hardwood clearcuts. pp. 40-47 in Proc. Seventh Central Hardwood For. Conf. Carbondale, IL.

Heiligmann, R.B., Norland, E.R., and Hilt, D.E. 1985. 28-year-old reproduction on five cutting practices in upland oak. North. J. Appl. For. 2:17-22.

Hilt, D.E. 1985a. Species composition of young central hardwood stands that develop after clearcutting. pp. 11-14 in Proc. Fifth Central Hardwood For. Conf. Champaign, IL.

Hilt, D.E. 1985b. Where has my yellow-poplar gone? North. J. Appl. For. 2:67-69.

Hix, D.M., and Lorimer, C.G. 1991. Early stand development on former oak sites in southwestern Wisconsin. For. Ecol. Manage. 42:169-193.

Host, G.E., Pregitzer, K.S., Ramm, C.W., Hart, J.B., and Cleland, D.T. 1987. Landform-mediated differences in successional pathways among upland forest ecosystems in northwestern Lower Michigan. For. Sci. 33:445-457.

Johnson, P.S. 1976. Modal development of regeneration in clearcut red oak stands in the Driftless Area. pp. 455-475 in Proc. First Central Hardwood For. Conf. Carbondale, IL.

Merz, R.W. and Boyce, S.G. 1958. Reproduction of upland hardwoods in southwestern Ohio. USDA Forest Service Central States Experiment Station Tech. Paper 155.

Myers, C.C., and Buchman, R.G. 1988. Silvicultural opportunities ten years after clearcutting central hardwoods. North. J. Appl. For. 5:22-25.

Oliver, C.D. 1982. Stand development — its uses and methods of study, in Mean, J. E. (ed.). 1982. Forest succession and stand development research in the Northwest. Symp. Proc. Oregon St. Univ., Corvallis, OR.

Redett, R. B., Barnard, J. E., and Dennis, D. F. 1982. Ohio's forests today. Ohio Woodlands 19: 9-12.

United States Department of Agriculture. 1989. Soil Survey of Hocking County, Ohio. Soil Conservtion Service. 236 p. U.S. Government Printing Office, Washington, D.C.

Walter, Russell S. 1963. Past growth of yellow-poplar and oak reproduction key to future. U.S. Forest Serv. Res. Paper CS-4.

Ward, J.S., and Heiligmann, R.B. 1990. Effect of site quality and season of clearcutting on hardwood regeneration in Ohio. North. J. Appl. For. 7:69-72.

Interactions Between Competing Vegetation, Herbivores, and Environmental Conditions Affecting Regeneration of Northern Red Oak (*Quercus rubra* L.)

David S. Buckley[1], Terry L. Sharik[1], Judson G. Isebrands[2], and William J. Mahalak[3]

Competing vegetation and herbivory are thought to contribute to regeneration failure of northern red oak (Quercus rubra L.) in the Great Lakes Region. Several studies have focused on these factors individually. Few have examined the interactions between discrete vegetation layers, environmental factors, and herbivores simultaneously. Objectives of this study were to compare the importance of vegetation in the herb, shrub, and canopy layers as competitors and to document changes in environmental and other factors produced by vegetation removal. Northern red oak acorns and 2 year-old nursery seedlings were planted in plots receiving various levels of overstory removal combined with understory vegetation removal. Overstory treatments consisted of a control and removal of overstory vegetation to produce 75% cover, 25% cover, and 0% cover. Understory treatments consisted of a control, removal of vegetation in the herb layer less than 25 cm tall, and removal of vegetation in the shrub layer 25 cm tall or greater. Plots were located in northern red oak and red pine (Pinus resinosa L.) stands on intermediate sites. Seedling performance and survival, vegetation characteristics, and environmental data were obtained during 1991-92. Along the gradient from no removal to complete vegetation removal, mean height growth increased by as much as 66% while the mortality rate from factors such as deer herbivory and frost increased from less than 1% to as high as 28%. These results indicate that the benefits of increased resource levels associated with low amounts of competing vegetation may be nullified, depending on the local incidence of deer herbivory and frost events.

---

[1] Michigan Technological University, Houghton, MI.

[2] USDA Forest Service, North Central Forest Experiment Station, Forestry Sciences Laboratory, Rhinelander, WI.

[3] Michigan Department of Natural Resources, Forest Management Division, Roscommon, MI.

Soil Nitrogen Mineralization and Cellulose Decomposition in Northern Red Oak Stands With Four Levels of Canopy Cover in Northern Lower Michigan

Choonsig Kim[1], Terry L. Sharik[1], Martin F. Jurgensen[1], Richard E. Dickson[2], and William J. Mahalak[3]

Abstract: Although the effects of partial canopy removal in northern red oak (*Quercus rubra* L.) regeneration have received considerable attention, the relationship between the rates of N mineralization or organic matter decomposition and various levels of canopy cover is not well documented. A series of experimental plots with four levels of canopy, i.e., 0% (clearcut), 25%, 75%, and 100% (uncut), was established in northern red oak stands in northern Lower Michigan. We examined net N mineralization using an *in situ* soil incubation technique and decomposition of cellulose filter papers in the top 15 cm of mineral soil during the second growing season (1992, May-October) following stand manipulation. There was a significant correlation between net N mineralization rates and cellulose mass loss. Net N mineralization rates for the growing season were 57.7 kg ha^{-1} for the clearcut, 54.2 kg ha^{-1} for 25% canopy cover, 50.6 kg ha^{-1} for 75% canopy cover, and 21.8 kg ha^{-1} for the uncut treatment. Net N mineralization rates were significantly greater in canopy removal treatments than in the uncut treatment. However, there was no significant difference in net N mineralization rates among the three levels of canopy removal. These results indicate that even only small amounts of canopy removal (leaving 75% canopy cover) are sufficient to cause substantial increases the amount nitrogen available to oak seedlings.

---

[1] School of Forestry and Wood Products, Michigan Technological University, Houghton, MI 49931.

[2] USDA Forest Service, Rhinelander, WI 54501.

[3] Michigan DNR, Roscommon, MI 48653.

Effect of Ectomycorrhizae on 1-year-old Northern Red Oak Seedlings in Response to Overstory and Understory Manipulations in Oak and Pine Stands

Minyi Zhou[1], Terry L. Sharik[1], Martin F. Jurgensen[1], Dana L. Richter[1], and William J. Mahalak[2]

Abstract: Development of ectomycorrhizae (ECM) and establishment of northern red oak (*Quercus rubra* L.) seedlings in response to overstory and understory manipulations were studied in oak and pine forests in northern Lower Michigan. A split-plot experimental design was employed with four levels of canopy cover (0, 50, 75 and 100% (uncut)) and two understory treatments (shrub removal and untreated). Northern red oak seeds from a common source were sown in each treatment. The ECM were classified and quantified by morphological type for emerged seedlings in the first growing season. Seedling growth and its relation to mycorrhizal colonization were evaluated. A higher ECM density (no./g) of northern red oak seedlings was found in pine stands than in oak stands. ECM colonization was significantly greater in seedlings under 50% canopy cover than in those under other canopy covers. No significant difference was found in ECM development between understory treatments. Black-type ECM (*Cenococcum geophilum* Fr.) was highest soil moisture and temperatures occurred. White-type ECM was associated with increases in stem diameter, leaf area and total biomass of the seedlings. A positive relationship was found between root/shoot ratio and total ECM density. These results suggest that conditions associated with partial canopy cover stimulate ECM development of northern red oak and may also help to explain the greater success of northern red oak regeneration beneath pines than beneath oaks.

---

[1] School of Forestry and Wood Products, Michigan Technological University, Houghton, MI 49931.

[2] Michigan DNR, Roscommon, MI 48653.

Groundfire Effects in a Sapling-sized Oak-maple

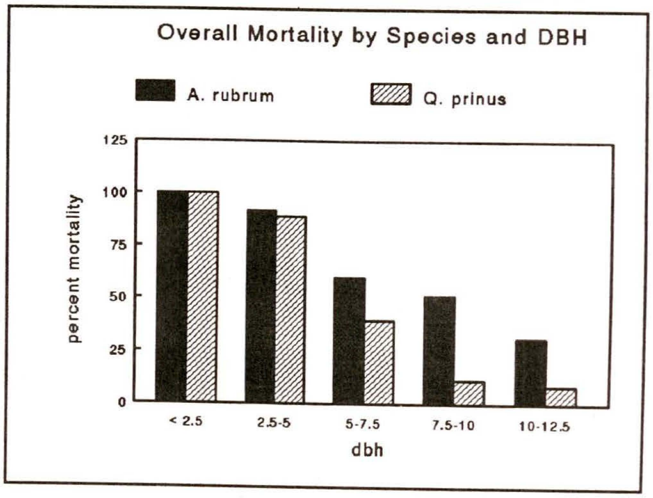
Jeffrey W. Stringer[1]

Abstract: Prescribed fire has often been suggested as a treatment for reducing maple competition in sapling- and pole-sized mixed oak-maple stands. The relatively thin outer bark of young *Acer* spp. makes them more susceptible to fire damage than many co-occurring *Quercus* spp. However, specific fire regimes to produce adequate maple control while providing limited degradation of the oak component have not been developed. Fire parameters, such as time of burn, intensity, duration, etc., coupled with vegetative responses are needed to accomplish this. This type of detailed information can generally only be obtained from experimental prescribed burns. However, useful information can be obtained from monitoring the effects of wildfires. In the latter instance, detailed intensity and duration information are generally lacking, however indicators of fire damage such as scorch and char have been used to predict mortality from wildfires and can provide useful information about inter-specific mortality from fires.

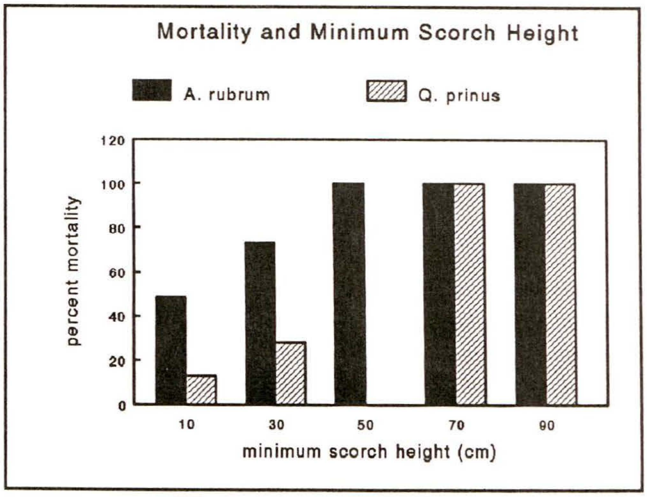
This poster abstract describes the first-year effects of a fall groundfire which passed through a sapling-sized (mean dbh = 7.8 cm) stand dominated by *Acer rubrum* and *Quercus prinus* trees (n=344). The stand was on an upland site at Robinson Experimental Forest on the Cumberland Plateau in eastern Kentucky. One year prior to the burn, trees in one-half of the stand were released using a crown-touching technique. Post fire inventory included individual tree measures of dbh, minimum and maximum scorch height, percent circumference scorched, and percent bole surface area scorched. Mortality data was collected at the end of the growing season. Data was collected for all trees in the stand and trees were classed into 2.5 cm dbh classes, providing 5 dbh classes ranging from < 2.5 cm to 10-12.5 cm. Correlations between fire indicators and species mortality were made within dbh classes to provide information which could be used to predict species mortality for oak-maple stands of varying mean diameters. Overall mortality averaged 62% for *A. rubrum* and 26% for *Q. prinus*.

---

[1] Research Specialist in Silviculture, Department of Forestry, University of Kentucky, Lexington, KY, 40546-0073



Mortality was negatively correlated with dbh (Figure 1). Approximately 90% of stems < 5 cm dbh of both species died. However, mortality decreased with increasing diameter to 42% for *A. rubrum* trees between 10-12.5 cm dbh and 0% for *Q. prinus* trees of the same diameter. No differences in mortality were found between released and unreleased *Q. prinus* trees averaging 25.3 and 26.9 percent, respectively. However, the mortality percent of released and unreleased *A. rubrum* tree was significantly different ($P \leq 0.05$), averaging 76.5 and 47.8 percent, respectively. This difference was correlated with a greater amount of fuel under the released portion of the stand. Mortality was positively correlated with scorch heights. When minimum scorch heights were ≥ 60 cm, mortality was 100% regardless of diameter class and species (Figure 2).



Q. prinus mortality dropped to 17% with minimum scorch heights of 10 cm while *A. rubrum* mortality was 50% at this minimum scorch height.

★U.S. GOVERNMENT PRINTING OFFICE 1993 758 627 /80051

The policy of the United States Department of Agriculture Forest Service prohibits discrimination on the basis of race, color, national origin, age, religion, sex, or disability. Persons believing they have been discriminated against in any Forest Service related activity should write to: Chief, Forest Service, USDA, Washington, DC 20250.

Gillespie, Andrew R.; Parker, George R.; Pope, Phillip E.; Rink, George, eds. 1993. **Proceedings, 9th Central hardwood forest conference**; 1993 March 8-10; West Lafayette, IN. Gen. Tech. Rep. NC-161. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 515 p.

Proceedings of the Ninth Central Hardwood Forest Conference includes one invited paper, 39 volunteer papers, and 13 volunteer poster abstracts. Presentations encompassed forest biology, protection, silviculture, ecology, inventory, yield, economics, marketing, wildlife management, soils, and nutrition of the central hardwood forests.

KEY WORDS: Forest ecology, silviculture, protection, regeneration.

Our job at the North Central Forest Experiment Station is discovering and creating new knowledge and technology in the field of natural resources and conveying this information to the people who can use it. As a new generation of forests emerges in our region, managers are confronted with two unique challenges: (1) Dealing with the great diversity in composition, quality, and ownership of the forests, and (2) Reconciling the conflicting demands of the people who use them. Helping the forest manager meet these challenges while protecting the environment is what research at North Central is all about.

NORTH CENTRAL
FOREST
EXPERIMENT STATION